GEOLOGY

OF

ENGLAND AND WALES.

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Frontispiece.

THE

GEOLOGY OF ENGLAND AND WALES:

A CONCISE ACCOUNT OF

THE LITHOLOGICAL CHARACTERS, LEADING FOSSILS, AND ECONOMIC PRODUCTS OF THE ROCKS;

WITH NOTES on the PHYSICAL FEATURES of the COUNTRY.

BY

HORACE B. WOODWARD, F.G.S.

OF THE GEOLOGICAL SURVEY OF ENGLAND AND WALES.

WITH MAP AND WOODCUTS.

LONDON:

LONGMANS, GREEN, AND CO.

1876.

TO THE

Memory of his Father

DR. SAMUEL P. WOODWARD, A.L.S. F.G.S.

AUTHOR OF 'A MANUAL OF THE MOLLUSCA,'

This Book is Dedicated:

FOR TO HIS EARLY TEACHINGS AND INFLUENCE

THE WRITER IS LARGELY INDEBTED.

PREFACE.

The publication of a book intended to give an account of the Geology of England and Wales requires a few prefatory remarks from the writer who has to deal with so comprehensive a subject.

When, in the year 1822, the Reverend W. D. Conybeare and William Phillips issued their 'Outlines of the Geology of England and Wales,' the science had but commenced that rapid growth which has characterized it during the past fifty years. The philosophic teachings of Hutton, Playfair, and William Smith had as yet to be developed; and it was only after the true principles of Geology had been illustrated in the early writings of Scrope, and elaborated by De la Beche and Lyell, that its place among the Inductive Sciences was fully established.

No work has proved more useful to the field-geologist than that of Conybeare and Phillips; and, on account of its being essentially a record of facts, it is much appreciated and valued at the present day. But the labours of half a century have materially altered our views of the nomenclature and classification of the rocks, and increased to a very large extent our knowledge of their life-history. The work of the pioneers has been followed up by an ever-increasing band of geologists; while the labours of the Geological Survey, and those of the Palæontographical Society, have tended very greatly to the development of the science, in the eluci-

dation of the minute structure of our country, and in the determination of the varied forms of life which have been entombed in the rocks.

As a natural consequence the progress of Geology is accompanied by increasing detail and subdivision, and a work based on the Geological theories prevalent fifty years ago is clearly unsuited to the requirements of the present day. This work has consequently been undertaken with the view of supplying an obvious want, and, bearing in mind the paramount importance of using the hammer and chisel, it is specially intended to furnish a guide for those who go out into the field to study. The descriptions of the different strata will probably be sufficient, with the help of a geological map, to enable anyone to identify them in the field, while the fossils enumerated have been selected as those most abundant and characteristic.

So far as possible, all the local names of rocks, many of them geographical ones, have been given; and it has also been my aim to include all Synonyms, it being frequently impossible to understand the various papers on isolated questions or localities without information relative to them. It is unfortunate that this necessity should exist, as these varieties of nomenclature are as confusing to the student as they are detrimental to the progress of Geology.

The enumeration of the various economic products of the rocks, with the indication of their geological age, will, it is hoped, be found a useful feature in the work.

The formation of our scenery—one indeed of the most interesting of geological topics—has been sketched briefly, and with the endeavour to avoid giving undue prominence to any particular theory.

The Igneous and Metamorphic rocks have been treated less fully than those of a Sedimentary character for the reason that their history and nomenclature require further illustration

and greater precision than they have at present received. Many of the names given to these rocks, solely from inspection in the field, have not borne the test of microscopic and chemical investigation; but of late years considerable attention has been given to the subject, and the harvest of knowledge to be expected is great. In the mean time the Tables included in this work, which have been very kindly furnished to me by Mr. F. Rutley for the purpose of showing the classification of these rocks, cannot fail to prove useful to the student.

It may be thought that the Fossils have received too little notice, and I would gladly have said more about them, could I have done so with justice. But I considered that the insertion of mere lists of names, unaccompanied by figures, would have been of little benefit to the student in the field; nor could full lists, and figures of even the characteristic fossils, have been given without doubling the size of the volume. Moreover, Mr. W. H. Baily has for some time been engaged upon a series of 'Figures of Characteristic British Fossils, with Descriptive Remarks;' and he has published the Palæozoic portion. May his task soon be completed! Mr. Lowry, too, has engraved and published an excellent Chart of British Fossils, and a still more useful one of British Tertiary Fossils.[1] These will be found to answer most purposes of the student, who, as a rule, must be satisfied with determining the genus of any fossils he may collect, leaving the specific names to those whose special work lies in some department of Palæontology. Access, however, to the splendid Monographs published by the Palæontographical Society, or a comparison of his specimens with those exhibited in the cases of some Museum, will often enable the geologist to determine the species he has obtained.

[1] A special Chart of Fossil Crustacea was prepared by Messrs. J. W. Salter and Henry Woodward.

With regard to the subject of Classification, I have in most instances followed that which is adopted by the Geological Survey. But I have introduced some modifications in the classification of the Cambrian, Silurian, and Permian rocks, because they have the sanction of those high in authority, and because in such cases, where even the best of 'doctors' disagree, I have necessarily had to use my own judgment. In these instances I have not neglected to indicate the opinions thus opposed to each other. Questions of classification are, indeed, of little moment as affecting the truth of geological deductions, and as our knowledge increases, it becomes more and more difficult to define the exact limits of any one period so called, for the history of the earth is but the record of one continued series of more or less gradual changes in scene and in life.

It has been considered unnecessary to enter into much detail regarding the geographical distribution of each formation, as this can be best understood by reference to a Geological Map, such as that of Ramsay or Greenough, or the larger Map published in separate sheets by the Geological Survey. The Map accompanying this volume, which has been drawn by Mr. C. L. Griesbach, will be useful as an index-map, as it displays the geographical extent of the great groups of strata where they are exposed at the surface.

I had intended to give the Foreign Equivalents of our strata; but I must confess that I became bewildered with the multiplicity of names, and soon arrived at the conclusion that any effort to do justice to this subject would not only require the constant labour of many years, but would, after all, be somewhat similar to an effort to place in columns the reigns of the several contemporary kings, emperors, and other rulers of different countries, an effort which would entail little else but confusion by reason of the innumerable brackets that such a plan would render necessary. I have therefore strictly

confined myself to the geological history of England and Wales.

My task has been to gather together all the principal facts, and to arrange them as far as possible in systematic order. Such a record in itself can prove by no means of an entertaining nature. A 'Geology made interesting,' in the popular sense, must necessarily be free from details; but those who seek to understand the 'principles' will soon make the subject interesting to themselves, especially if they buckle on the hammer and go into the field to study.

Not the least difficult portion of my work has been the effort to give due credit to those whose labours are condensed in this volume. I have given a list of the principal publications which I have consulted, but I have refrained from burdening the text with references, believing that not only would this necessitate much repetition, but that in many cases, unless the foot-notes exceeded in bulk the other material, it would be invidious to enumerate the works wherein the facts were originally noticed and discussed. And in many instances it would be well nigh impossible, in a work of so general a nature as the present, to determine to whom we were first indebted for the indication of facts which, after all, would be patent to any observer, and may be regarded as common property. As Edward Forbes observed, the time will come when the author of a view shall be set aside, and the view only taken cognizance of.

To many friends and colleagues, however, I am particularly indebted; and firstly I must record very grateful thanks to my Uncle, Mr. Henry Woodward, who has ever been ready to give advice and assistance throughout the progress of the work.

To Professor Hughes I am indebted for many corrections and suggestions in the Cambrian and Silurian Chapters, and to Professor Green similarly in regard to the Carboniferous Chapter. Mr. Bristow and Mr. Etheridge kindly examined

the Oolitic Chapter; Mr. Topley revised the Lower Cretaceous portions of the book, and Mr. Whitaker those referring to Chalk and Eocene strata. To Professor Rupert Jones I am indebted for sundry remarks upon Chalk-flints; and to Mr. James Geikie for notes on the Glacial Period. I am likewise indebted to Mr. Rutley for several notes in addition to those on the classification of the Igneous and Metamorphic Rocks.

Lastly I must record my obligations to Mr. William Longman for the kindly interest he has taken in this work; and both to him and to Mr. C. Puller I must return thanks for many valuable hints and emendations with which they have furnished me while passing the work through the press.

The Diagram-sections are either original or from acknowledged sources. The pictorial sections have been prepared by my friend Mr. Edward Fielding, some from photographs, others from very rough drawings furnished by myself; and all the woodcuts have been engraved by Mr. G. Shayler.

While I acknowledge the kind assistance of friends, I must add that they are by no means responsible for any errors or omissions that may be found in the chapters they have looked over, nor for any of the opinions given, except where expressly stated. Notices of all errors and omissions will be gratefully received, with, it is hoped, a full pardon for such transgressions.

HORACE B. WOODWARD.

8th July, 1876.

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EXPLANATION OF MAP.

As the Map accompanying this volume differs in some respects from other geological maps of England and Wales, it may be well briefly to indicate the changes introduced.

The index of colours has been arranged to show the comparative thicknesses of the formations.

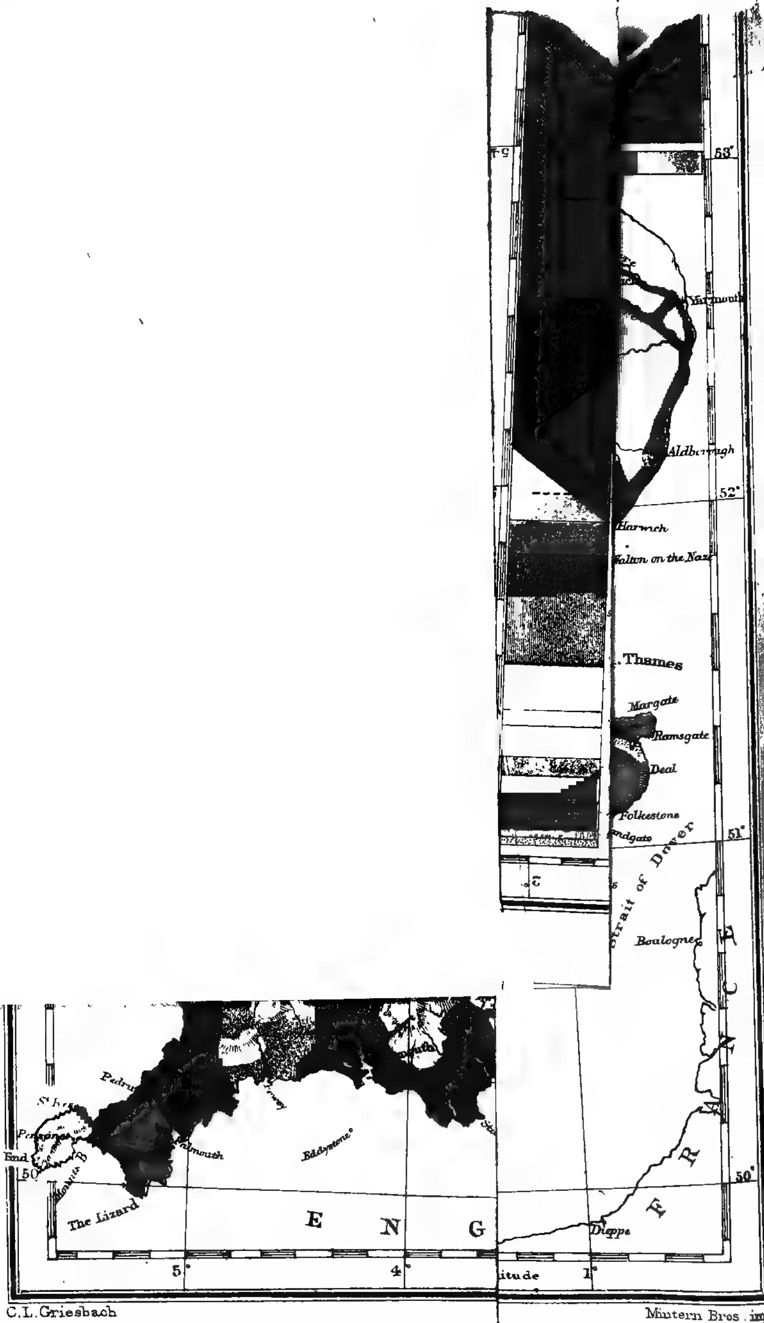
The Cambrian and Silurian rocks are classified according to Sedgwick, so that the former group includes the Lower Silurian of Murchison.

The Devonian rocks are shown in the index as representing portions of both Old Red Sandstone and Lower Carboniferous Rocks, which seems to be their true position in the geological scale.

The Neocomian (Wealden and Lower Greensand) or Lower Cretaceous strata are separated from the true or Upper Cretaceous strata.

The Drift deposits (Boulder Clay and Gravels) which it is attempted to show, comprise a very small portion of those which are scattered over the greater part of the country; but as yet they have been mapped only in certain areas where they are perhaps most extensively developed, and these areas are shown. It must be remembered, however, that while they obscure so much of the Chalk and Tertiary strata in the Eastern counties, these older deposits are generally exposed in the valleys, although in tracts too small to display them upon the Map.

LIST OF WOODCUTS.



C.L. Griesbach

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GEOLOGY

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ENGLAND AND WALES.

INTRODUCTION.

GEOLOGY in its widest interpretation is a History of the Earth. Its object is to enquire into the nature of the changes which the Earth has undergone from the beginning. The alterations which are now taking place on its surface in the continual waste of the land by rain, rivers, and sea; the dispersion and deposition of the material thus removed; the phenomena of earthquakes and volcanoes; the rising of land in one place, and its sinking in another; the distribution of animal and vegetable life, their growth and decay—all these incessant changes are but the continuation of the Earth's past history which we read in the consolidated mud, sand, and ooze with their included fossilized remains of animals and plants, and in the old volcanic rocks, which together constitute the outer coating or crust of the Earth. Thus the phenomena now produced by causes we can for the most part see and examine have arisen in past times from similar causes, and continued to do so during a period of time so vast that we cannot realise its length. The very beginning we can but dimly picture and speculate upon, and we need not enter upon this subject, as the special province of the geologist is only to deal with the Earth after

it was in a fit state to receive and support life, when the proportion of land to water was probably much as it is now, and the climate and physical conditions, though ever varying over the same area during the different geological ages, were subject to the same laws and attended by analogous phenomena. Nowhere do we detect any evidence of abrupt physical change or universal catastrophe: on the contrary, through every epoch we can discern a Uniformity in cause not only in the inorganic, but also in the organic world, accompanied though it be by evidences of Evolution or the gradual development of higher and higher forms of life.

To go back to the very earliest history of the Earth, when it was part of a nebulous mass, would be to trespass upon the region of the Astronomer; and when we consider its latest history, we come upon questions which must be answered by the Geographer and the Archæologist.

In all such questions, however, we must not limit our ideas to what we see in our small tract of the British Islands; nor must we, in concluding that the physical forces have been the same throughout geological time, suppose that their action has been always of similar intensity to that of which we have definite proof in the present.

The changes we have to deal with are those represented by the crust of the Earth, or that part of it which alone is accessible to human observation. This crust is composed of different rocks which are arranged according to their method of formation into four classes—1. *Aqueous,* or *Sedimentary*;[1] 2. *Sub-aërial*; 3. *Igneous*, or *Eruptive*; and 4. *Metamorphic.*

1. *Aqueous*, or *Sedimentary Rocks.*—These include most rocks deposited under water, as Sand, Sandstone, Clay, Shale, Marl, Chalk, Limestone.

2. *Sub-aërial Rocks.*—These include deposits formed on land, as Peat, Còal, Æolian or Blown Sand.

[1] Sometimes called *Neptunian.*

3. *Igneous*, or *Eruptive Rocks.*—These include the rocks which have been intruded as bosses and dykes, or have been poured out as lava-flows, or ashes from volcanic centres, as Basalt, Greenstone, Trachyte, Felstone, Porphyry, Granite, &c.

4. *Metamorphic Rocks.*—These include rocks which have undergone great alteration by heat and pressure, as Granite? Mica-Schist, Gneiss, some kinds of Marble, Slate, &c.

The arrangement and characters of the AQUEOUS, or SEDIMENTARY rocks will be seen from the accompanying Table:—

	When indurated or compacted	Lithological constitution, or chief Mineral ingredients	Metamorphosed
Gravel	Breccia or conglomerate	Angular, sub-angular, and rolled fragments of all kinds of rocks	...
Shingle, Pebble-beds	Conglomerate or Pudding-stone	Pebbles of hard rocks, such as limestone, flint, sandstone, quartz, quartzite	... Grauwacké, or Greywacke.
Sand	Sandstone and Grit[1]	Quartz grains sometimes cemented by calcareous matter: fine-grained siliceous rock	Quartzite
Loam or Brick-earth	Mudstone	Clay and sand	Slate (when cleaved)
Clay	Shale	Silicate of alumina	
Marl	Marlstone	Clay and carb. lime: Argillaceous limestone.	Marble in some instances.
Calcareous mud or Ooze	Limestone[2]	Carbonate of lime (chiefly)	

[1] The terms grit and sandstone are used very indefinitely. Mr. F. Rutley describes Grit as 'a coarse-grained and somewhat coherent, or, at times, a fine-grained and very hard compact sandstone, frequently containing fragments and granules of other minerals beside Quartz, Flint, or Chert.'

[2] Any limestone and some other rocks of ornamental character, if capable of being polished, are called Marble.

The AQUEOUS OR SEDIMENTARY and SUB-AËRIAL ROCKS may be again classified, according to their method of formation, thus:—

1. *Mechanically formed.*

Gravel, Sand, Conglomerate, Breccia,[1] Clay, Shale, Loam, Marl, some Limestones.

2. *Chemically formed.*

Dolomite, Tufa, Iron-stone, Nodules and Septaria, Rock-salt, Flint,[2] Chert,[2] some Limestones, Gypsum.

3. *Organically formed.*

Some Limestones, Coal, Lignite, Peat.

In all attempts to classify the rocks, we find, however, that hard lines of separation do not exist, as many agencies work together in their formation. Deposits formed by chemical action are mingled with organic remains and with mechanically formed sediment.

Some limestones may be merely eroded granules of pre-existing limestone carried mechanically in suspension in water, and ultimately deposited as a sediment. Some may have resulted from the precipitation of carbonate of lime from water holding the bi-carbonate of lime in solution. In this case the deposit may be considered to have a chemical origin. Travertine, calcareous Tufa, and Pisolite, are rocks formed in this manner. The last-named consists of rounded grains like shot or peas, whence the name Pisolite, or Pea-stone—the finer varieties being termed Oolite or Roe-stone.

Limestones may also at times be composed in great part of the minute calcareous tests or shells of Foraminifera, or of the shells of other organisms; or they may be largely due

[1] Fault-rock, or the material filling up the crevices of faults, may be included here.

[2] Partly formed organically.

to the secretion of carbonate of lime by Corals. These rocks may be termed of organic origin.

Again, the siliceous matter in beds of chert and in nodules of flint may be due in the first instances to the accumulation of organisms having siliceous structures, but the formation of the beds and nodules themselves is evidently due to inorganic—chemical or physical—agency.

Deposits of very varied origin may be commingled in the neighbourhood of active Volcanoes, the ashes from which are frequently carried to great distances, and may be deposited on the ocean-bed as a sedimentary deposit, together with organic and other accumulations.

To turn to the subject of Igneous rocks, we find that although a study of the volcanic phenomena that are presented to our view at the present day throws considerable light on their former history, yet our opportunities of observation are necessarily limited to the rocks now thrown up at the surface, whereas many of the old igneous rocks, belonging to the various geological epochs, have evidently been formed or intruded at a depth below the surface, and have perhaps never appeared to the light of day, until, in comparatively recent times, disturbances and denudation have together assisted to reveal them.

Igneous rocks are of all ages, and occur as bosses and dykes bursting through and penetrating the stratified rocks. Sometimes they have flowed over a surface upon which other beds were afterwards deposited, so that they are intercalated with these rocks; at others they have forced their way between already hardened beds, and given a false appearance of contemporaneity.

Rocks, too, which were once deposited under water, have, by contact with igneous rocks, or through pressure, lost their original stratified character, and become altered or metamorphic. All rocks, indeed, are in a certain sense

metamorphic, as all have undergone some changes, however trifling they may be, since their formation; but they are not usually termed metamorphic unless their original structure is much obscured.[1]

The study of rock-masses, of bedding, stratification, and other features only to be observed in the field, is called Petrology; the study of rocks in respect of their mineral composition and microscopic structure is called Lithology.

There can be no doubt that the aqueous rocks, as a rule, were formed and deposited on the ocean-bed in the same way as such rocks are now accumulated—the pebble-beds and sands near the shore, the clayey and marly beds, and the limestones in the deeper water. Gravel, sand, and clay are likewise formed by rivers and glaciers, and all kinds of sediment may be deposited in lakes.

It may be noticed on any sea-coast where there are cliffs, how the ceaseless action of the breakers is ever wearing away the rocks. Great portions of the cliffs are undermined, and masses fall down and are pounded up by the waves into shingle and sand. The finer matter is often carried to some distance from the shore and laid down at the bottom of the ocean. Thus in time great deposits are formed.

Again all rivers bear along with them much material held in suspension, which has been worn away from their banks or carried into them by springs and rivulets, and this they carry into the sea or lake, as the case may be; the heavier materials naturally sinking first, and the finer or lighter particles being carried to the greatest distance.

The stratified rocks occurring one above the other form a series, which is however subject to much modification.

We find throughout all time, that while deposits have

[1] As the classification of these rocks is given in the chapter on the Igneous and Metamorphic Rocks, it is unnecessary to say more about them here.

been forming very much as they do now in limited areas, the areas have continually changed from dry land to water, and *vice versâ*. The deposits formed have been upheaved, and partly worn away or denuded; fresh ones have been afterwards spread over their worn surfaces; and thus, although there is a certain regularity, the series, as we shall see, is marked by the local absence of many of its members.

Our English and Welsh rocks are mostly of the aqueous or sedimentary kind—rocks deposited under water, and arranged in layers or 'strata,' whence they are called stratified. And it may be safely assumed that all such beds were originally deposited in an approximately horizontal position, and that any considerable deviation from this, such as is often exhibited by the planes of bedding, is due to subsequent disturbance.

It is true that we have clay, limestone and marl, sandstone, sand and conglomerate, intercalated one with another, occurring at all horizons in the earth's crust, generally harder or more compact the older they are; but it is well known that these rocks are arranged in a certain regular series, distinguished one from another by peculiar mineral characters, and by the occurrence in them of particular fossils, and that the newer the rocks in which these latter are embedded, the more closely are they allied to the forms of life now in existence.

All those who have travelled have no doubt observed the different character of the rocks in different places—in one locality chalk, in another sandstone; here clay, there slate or limestone; but the difficulty is to comprehend the relation that one rock bears to another, and to understand their sequence.

The relations of the different strata have been determined by actual observation of one set of beds superimposed on another in many cliffs, quarries, and railway-cuttings, and by the records of deep mines and wells. When such evidence

is not to be obtained, the stratigraphical position of a set of formations may be determined by the actual mapping of them, by tracing out their extension across country, noticing the dips, springs, form of the ground, &c. When these relations have been ascertained, the palæontological history of the strata can be written, and this will furnish a key to the identification of isolated masses of strata.

To quote the Rev. W. D. Conybeare,—'If we suppose an intelligent traveller taking his departure from our metropolis, to make from that point several successive journeys to various parts of the island, for instance to South Wales, or to North Wales, or to Cumberland, or to Northumberland, he cannot fail to notice (if he pays any attention to the physical geography of the country through which he passes) that before he arrives at the districts in which coal is found, he will first pass a tract of clay and sand; then another of chalk; that he will next observe numerous quarries of the calcareous freestone employed in architecture; that he will afterwards pass a broad zone of red marl and sand; and beyond this will find himself in the midst of coal mines and iron furnaces. This order he will find to be invariably the same, whichever of the routes above indicated he pursues; and if he proceeds further, he will perceive that near the limits of the coal-fields he will generally observe hills of the same kind of compact limestone, affording grey and dark marbles, and abounding in mines of lead and zinc; and at a yet greater distance, mountainous tracts in which roofing slate abounds, and the mines are yet more valuable; and lastly, he will often find, surrounded by these slaty tracts, central groups of granitic rocks.'

And it is this regular order which enables us to form our tables of strata, showing the oldest known rocks to be the Laurentian, and the newest the Alluvial deposits of our rivers and the beaches along our coasts.

When, however, we come to take the estimated thickness of the known strata, and this is something like 70,000 to 100,000 feet, and compare it with what we know of the earth's crust through the deepest boring, which is little over one mile in extent (5,570 feet), we at once see what changes, denudations, and dislocations the crust has undergone, by means of which the older rocks are brought to the surface. The crust of the earth may be as much as 800 miles in thickness, but on this point great uncertainty necessarily exists.

The arrangement of our stratified rocks has been aptly compared to layers of cloth of various colours and irregular shapes overlying and overlapping one another; some squeezed or rucked up, with even layers deposited upon them. Each layer may be taken to represent a series of limestones and clays, or sandstones and conglomerates, or slates. Some layers, the lowest ones perhaps, may be rucked up into mounds higher than all the rest, and yet they are clearly the oldest, because they may be traced in places underneath those at a lower level. Indeed, we find as a rule, that the older the rocks, the more wild, rugged, and mountainous is the nature of the ground they occupy; for these rocks have of course undergone more induration and elevation from heat and pressure than the rocks formed subsequently to them; and they have often been elevated to form land for long periods, while newer deposits were forming around them, which indeed were made up to a large extent from their destruction. Some of our rucked layers of cloth should have the summits of their folds cut off to represent denudation or wearing away which took place before the layers above were deposited: this is called an *unconformability*, and is a sure indication of a long interval of time. Next when we have our pile of cloths thus arranged, we may cut imaginary valleys out of them, and then the different coloured pieces

that are exposed on looking at the surface of the whole mass would give a very good idea of the phenomena exhibited by a geological map. Illustrations of this kind in wood have been prepared by Mr. Sopwith, and they form admirable models for the student. [1]

From this arrangement it will be seen that there is much uncertainty in the distribution of the strata, but that their order is never inverted except in some rare cases of disturbance, and then only over a small area. The older rocks are often at the surface where the newer have either never been deposited upon them, or have been subsequently denuded. Consequently in coal-mining, it is always easy for a geologist to say that coal *cannot* be found where the rock at the surface is older than the coal-measures, but it requires much consideration to say where it *might* be found, and if so at what depth, when newer rocks are at the surface.

Our rocks are divided into numerous systems, and groups, and minor subdivisions, all of which, when looked at in a large way, are seen to be merely terms of convenience. The history of the earth, so far as we know it, shows a sequence of events uninterrupted by any universal physical break; and so when we find one rock deposited on the eroded surface or upturned edges of another of a much older date, we are justified in looking elsewhere for the missing sedimentary formation, and we are frequently successful in the search. The British Islands, and even England and Wales, although not entirely complete in the succession of rocks comprised within their limits, present a very fair record of the periods embraced in the history of the earth's crust, and so far as we know furnish a history more complete than that of any other tract of similar extent. It might be imagined that this completeness of the geological record was due in great measure to the fact

[1] An Article by the Author on *How to Make a Geological Map* was published in the *Popular Science Review* for January, 1873.

that our islands have been more carefully and thoroughly investigated than any other portions of land. But although this has certainly been done, the fulness of the record depends more on the continuous succession of the strata, and the fewness of great breaks in it, aided in some instances by the succession of organic life which characterizes the different formations.

Nevertheless, it must always be remembered that the geological history of England is not the geological history of the world, any more than the history of the English people is the history of all nations. We could not expect that the changes affecting England and Wales should have been ac companied by similar changes over a large extent of the earth's surface. Our coal-bearing period was not a coal-bearing period all over the world, nor did the organic species found in our rocks exist simultaneously over wide areas.

Rocks, for convenience of study and of description, are divided by geologists into various systems and groups. The term Formation, as defined by Lyell, means an assemblage of rocks which have some character in common, whether of origin, age, or composition. Thus we may speak by way of contrast of stratified and unstratified formations, and in like manner of freshwater and marine, aqueous and volcanic, ancient and modern, metalliferous and non-metalliferous formations.

The term System is generally applied to groups of strata intimately connected, such as the Carboniferous System, the Silurian System, the Cambrian System.

The term Cycle is applied to the three great divisions in time of Palæozoic, Mesozoic, and Kainozoic.

No particular restriction can be given to the use of the terms Series, Groups; nor to those of Beds, Rocks, Strata, and Deposits. In many cases, however, it is more convenient to use the term Beds than one indicating a particular

lithological character, such as Thanet Beds instead of Thanet Sand; but in others, such terms as Red Crag, Portland Stone, Oxford Clay, Coral Rag, Old Red Sandstone are to be preferred.

The majority of the formations are of marine origin; that is to say, they were deposited on the sea bottom: though we do here and there, and particularly in the Coal-measures, in the Wealden beds, and in our peat-mosses, find evidence of terrestrial and fluviatile deposits.[1] But this furnishes no reason for supposing that the bulk of the material was worn from the old lands by marine action. The amount of sediment brought down by rivers far exceeds that worn away from the land by the sea. The deposits actually formed on the land, so to speak—the Sub-aërial rocks as they are called—are comparatively trifling; and we must remember that so many changes have taken place, that the old land deposits, old soils, river sediments and lake deposits have been, except in a few instances, obliterated: for the old land has been continually destroyed to form new strata on the ocean bed.

The stratified rocks generally contain remains of the plants and animals which existed at the time of their formation. Of the latter the most conspicuous are the shells of Mollusca and Crustacea, stony Corals, Sea-urchins, bones and teeth of Fishes, Reptiles and Mammalia. These are called fossils. The rocks are also liable to contain the organic remains of pre-existing periods, just in the same way as fossils are often found mingled with the recent shells in our present shore-deposits. These may frequently be detected by their rolled or fragmentary condition, or by being accompanied by a portion of the matrix of the rock in which they were first embedded.

[1] The saltness of the sea must have been very much as it is now since the earliest times, and the question of its origin is one which concerns Cosmogony rather than Geology. See D. Forbes, *Geol. Mag.*, vol. iv. p. 438.

The fossils proper to a formation furnish us with a key to its age, and the mode of its accumulation, whether by fresh-water, estuarine, or marine agencies.

In identifying a deposit by its organic remains, it must, however, be borne in mind that not only do the sedimentary conditions of one period vary in different places, but that the forms of life whose existence depends largely upon the conditions, likewise vary in different localities.

Distinct faunas may be separated by narrow barriers in existing seas; and differences almost as great may occur on the same coast-line without the interposition of any barrier, merely in passing from a sea-bed of rock and weed to one of sand or mud, or to a zone of different depth. It would be unreasonable to expect the same fossils in a limestone as in a sandstone; and even in comparing similar strata we must consider the probability of their having been formed at different depths, or in distinct zoological provinces.[1]

Further, in studying the fossils of any particular formation we must expect an admixture of marine forms that could not have existed together in the same depth of water, as forms which frequent shallow water would sometimes be drifted into deeper sea.

In classifying and correlating different deposits there are many circumstances to be taken into consideration, and it will be seen that often it is impossible to prove contemporaneity, and that the term 'homotaxeous,' used by Professor Huxley, is more convenient to express similar relative position without necessarily meaning identical age.

Thus the term Gault refers to the *clayey* beds that occur between the Upper and Lower Greensand (or Neocomian), but the Gault may not be persistent as a clayey stratum everywhere at this horizon: for instance, at the Blackdown Hills in Devonshire it may be represented in part by a stratum of sand. It

[1] See the *Manual of Mollusca*, by S. P. Woodward.

would, however, only tend to produce confusion in our geological tables were we to designate a certain part of the Blackdown Greensand as Gault. Where the Kimeridge and Oxford clays come together without the intervention of the Coral Rag series, we might identify portions of the clay as probably synchronous with the absent limestones and sands, but it would obviously be absurd to term portions of the clay Coral Rag. The same may be said regarding the Speeton clay; or of the Midford sands, which in one place might be called Upper Lias and in another Inferior Oolite! Our geological terms must be essentially lithological ones.

Strata may be therefore identified by (1) Position, (2) Mineral Characters, (3) Organic Remains.

The study of Fossils, or Palæontology, is intimately connected with Zoology: one must be acquainted with living forms to properly interpret extinct forms of life, in the same way as one must illustrate the earth's past history by studying the changes now in progress.

The number of British fossils, amounting to about 13,000 species (according to Mr. Etheridge), may well appal those who would attempt to identify the fossils they collect. Palæontologists themselves devote their particular attention to certain sub-kingdoms or classes of animals, and the determination of species for scientific purposes must be left to them.

The wholesome spread of the Darwinian theory has tended rather to reduce the number of species, but of course new forms will continually be discovered, and they must be named. But as Prof. Huxley has intimated, the less regard Palæontologists pay to the deposit from which fossils are obtained so much the better, for not unfrequently has a new name been given to a known fossil because it has been found in strata where it was previously unknown. He even went so far as to express a hope that a race of Palæontologists might arise who were

utterly ignorant of geology, so that their labours might be regulated on purely zoological considerations!

Although, in the following pages, descriptions of each formation will be given, it must be borne in mind that such descriptions refer only to the main or characteristic lithological features. Hand-specimens might be collected which would be characteristic of each formation, and yet hand-specimens might be collected of Silurian, Carboniferous, and Lias limestones, which would seem identical in character; or of Lias clay, Oxford clay, and Kimeridge clay, which could not be distinguished; or of Old Red Sandstone, Coal-measure Sandstone, and New Red Sandstone of exactly similar composition.

Petrology and geological mapping can only be learnt and understood by field-experience: much detailed work is necessary to unravel the geological structure of any portion of country. The lines drawn upon a geological map may often seem imaginary to those casually glancing at a tract of land devoid of quarries and pit-sections; but the experience gained during long survey, the comparisons which can be made in bordering tracts from exposures of the strata and the form of the ground, the phenomena of springs and sometimes of soils, will enable the geological surveyor to infer with great approximation to truth the lines of outcrop or the boundaries of the several formations in an obscure country. The observation of the dip of the strata, and their ascertained thickness taken in conjunction with the features before-mentioned, are the general guides by which the field-geologist would draw the boundary-lines between formations in the absence of more positive evidence.

When for the first time in our lives we decide to give some attention to geology, we find that much hard study is necessary before the grand principles of the science are comprehended. Not only must we read one or more of the

leading Manuals, and make ourselves conversant with what is known of the order and life-contents of the various rocks, but we must go into the field, and examine for ourselves, in quarries, cliffs, and cuttings, the nature and arrangement of the rocks. We soon learn that Geology does not consist in the mere collecting and naming of rocks and fossils: but that it ultimately aims at restoring in imagination the successive changes through which the earth has passed, at picturing the different distribution of land and water in successive periods, the changes in climate, the character of the animal and vegetable life that has existed, and the indications furnished of a gradual succession of living beings which, through a development of higher and higher types, led up finally to the appearance of man upon the earth.

The deductions of geology rest upon the accumulation of a vast number of facts—facts which in themselves are often dry and tedious.

Thus the very detailed work of the Palæontologist—the determination and description of species of organic remains, derives its interest and importance from the light that any fossil or set of fossils may throw upon the past history of the earth, or upon the development of life. The intimate structure of a rock is interesting and important, as it sheds light on the character of the deposits of which it is a fragment, and which were accumulated in by-gone times, whether by volcanic agency, by rain, rivers, or sea.

When once the philosophy of Geology is understood, its history can be appreciated, and without reference to details. When we contemplate the beauties of a cathedral, we do not minutely study the character of the stone, or the way each block is placed; we admire the result, so long as we can see in it truth and harmony. It is the same with geology. We admire the results of geological investigation. We are glad to learn the past history of our globe,

and the meaning of its diversified features; to read the riddle of the rocks, and to speculate by what means and in what distant ages the fossils came to be embedded in them. And in the course of such a study of the structure of the earth there are disclosed to us such proofs of foresight and adaptation, the evidence of handiwork so grand and mysterious, that we can but wonder and reverence, and ponder on the meaning of these things. And yet we cannot grasp all the details of the grand fabric. Unless a man be constantly at work on a particular subject, he cannot keep his hold upon the details of it. We may study a cathedral, and we may carry away with us a grand conception of the whole, but to remember every feature of its architecture is beyond us.

Geology is no longer in its infancy. This may seem a bold assertion, considering how little we know of the stony structure of the bulk of the earth, or its surface. But enough has been done to prove that Geology is based upon a sound foundation. We may have to modify our notions of time, of the intensity of forces in by-gone periods as compared with those whose action we now witness; but such corrections would not interfere with the general truth of Geological deductions. We have much to learn about the transmutation of species, about the causes of great changes of climate, about the origin and metamorphism of rocks, and about the origin and antiquity of man; but the main outlines of the picture have been sketched, and it only remains to fill in the details. Some portions may have to be rubbed out, but they will not affect the general result that is foreshadowed.

In regard to Geological time as compared with Historical time, but little can be said with certainty.

The total thickness of the known sedimentary strata of the British Isles has been estimated by Professor Phillips at 72,584 feet. But we must not unite the thicknesses of the strata at their maximum, and say the sum total represents

the thickness of our stratified rocks. The varying thicknesses and characters of our formations may, in my opinion, be frequently accounted for by considering that the changes in physical conditions did not take place uniformly, but that a clayey, a sandy, or a calcareous formation may have occupied a longer period in its deposition in one locality than in another, while the succeeding formation may tell of conditions which locally were of shorter duration. An estimate of 55,000 feet seems to me to be a reasonable computation for the total thickness of strata represented in England and Wales.

We cannot, however, be exact in our measurements, nor is it possible to calculate with certainty the amount of strata unrepresented in our Islands. Professor Ramsay, indeed, would lead us to believe that the strata unrepresented were as great as, perhaps greater than, those preserved to us. It is true that we know but little of the very earliest or Pre-Cambrian strata: between them and the Cambrian there is evidence of a great break. Again there is considered to be an unconformability between the Cambrian and Silurian strata of Sedgwick; there is a great palæontological and physical break between the Chalk and the Tertiaries; and between our Eocene and Pliocene there is a break, which is partly bridged over by the Miocene deposit of Bovey Tracey. Locally, of course, there are many unconformabilities, but I believe that on the whole the succession of strata in England and Wales is far more complete than is generally taught, and that even the breaks above indicated, excepting only that between the presumed Laurentian and Cambrian, do not necessarily indicate any *very great* interval of time. And I should consider that the whole time which has elapsed from the beginning of the formation of the known strata might be fairly represented by estimating their total thickness at 75,000 feet, and supposing them to have been deposited uniformly and without break.

Sir William Thomson has calculated that the sun has probably not illuminated the earth for 100,000,000 years, and almost certainly not for 500,000,000 years. This gives a limit to our estimates of time which, notwithstanding its vagueness, we should be careful not to overstep.

The question has naturally arisen as to whether this estimated period of time is sufficient for all geological changes. Taking 100,000 feet as a full allowance for the total thickness of stratified rocks containing traces of life, Professor Huxley has pointed out that, restricting the time to 100,000,000 years, the deposits may be estimated to have taken place at the rate of $\frac{1}{1000}$ of a foot, or $\frac{1}{83}$ of an inch per annum. If we take 75,000 feet as an estimate, we may, for a similar period, calculate the rate of deposit at about $\frac{1}{100}$ of an inch per annum. And this is a rate which no one can consider as too rapid. The important fact must not be overlooked, that in the very earliest geological periods each bed of sand, clay, shingle, or limestone had actually to be formed; whereas in each succeeding period the fresh deposits were many of them largely made up of the older sedimentary strata; and therefore new deposits *may be* laid down more rapidly at the present day than could have been the case in former times.

Whatever estimate prove correct, however, there is no doubt that geological time has been 'inconceivably great'—every one will admit this, because the mind cannot realise the amount—'it eludes the grasp of both memory and imagination.'

The following Table shows the classification adopted in this book, the names of authors being appended to the terms which they have introduced :—

TABLE OF GEOLOGICAL SYSTEMS.

	Periods or Cycles	Systems	
	Quaternary .	Post-Tertiary.	
Neozoic (Forbes)	Tertiary or Kainozoic (Phillips)	Pliocene (Lyell) Miocene (Lyell) Eocene (Lyell)	forming one system.
	Secondary or Mesozoic (Phillips)	Upper Cretaceous Neocomian (Thurmann)	Cretaceous (Fitton)
		Oolitic (Smith) Liassic	Jurassic
		Triassic (Bronn) Permian (Murchison)	Poikilitic (Conybeare).
	Primary or Palæozoic (Sedgwick)	Carboniferous (Conybeare) Devonian (Lonsdale) Old Red Sandstone Silurian (Murchison) Cambrian (Sedgwick) Laurentian (Logan)	

SECTION I.

PALÆOZOIC.

CHAPTER I.

LAURENTIAN—CAMBRIAN.

THE term Palæozoic, derived from words which mean 'ancient life,' is applied to the oldest known rocks that form the crust of the earth. They are the 'Primary' rocks with which the Geologist has to deal; and although this latter term is now but little used, as we are unable to state positively that the oldest rocks known to us were those first formed, yet it is not altogether inappropriate, as in the Primary or Palæozoic age we shall always include the earliest known rocks and those formed up to the close of our Coal period. The term is one of convenience rather than one defining any very great physical or palæontological break. Many authorities would place the Permian rocks among those of Palæozoic age, but they seem in their sedimentary character to be so closely allied to the newer Triassic rocks, that it appears to me best to adopt the old name Poikilitic as a comprehensive term for both Permian and Trias; and to place this great group at the base of the Mesozoic or Secondary strata, because the Triassic rocks are so inseparably connected through the Rhætic beds with the Lias and Oolites.

The terms Azoic (without life) and Eozoic (dawn of life) are now but little used, because by the discovery of organic structure in the very oldest known rock, the first has become erroneous when applied to the earliest stratified aqueous formations, and the second is really an unnecessary addition to our nomenclature.

In studying the rocks of Palæozoic age, it is well to

remember what a vast series of strata they constitute, although at the same time they do not enter so largely as the Secondary and Tertiary rocks into the superficial structure of our country. The total thickness of the Palæozoic series may be roughly estimated at 45,000 feet, whereas the total thickness of the newer strata cannot exceed 10,000 feet. Moreover in the latter, the several subdivisions are well marked, and as a rule easily recognised, for they have not suffered the alteration that the older rocks have. The number of main subdivisions in the Palæozoic series is roughly similar to those identified and mapped out in the Secondary strata. But it must be observed that the number of minor subdivisions increases as we ascend the geological scale and reach the more recent deposits. In the lower divisions of the Palæozoic rocks the rarity and frequent obscurity of the organic remains, the difficulty in identifying the strata, and often of determining the true dip, have no doubt considerably reduced the number of geologists who have particularly studied these rocks. The Carboniferous rocks as a rule are readily recognised, but the exact age of the Devonian strata is a subject still under discussion.

The Palæozoic rocks possess generally a more crystalline and slaty structure than the newer strata; they are also more highly inclined and faulted, more frequently contorted, and more affected by igneous intrusion and metamorphism. They generally occupy more elevated ground, forming lofty hills and mountains, and are comparatively destitute of vegetation. They are the principal repositories, in England and Wales, of metallic wealth, and of coal.

The Palæozoic series is marked by the presence of fishes with heterocercal (unequal-lobed) tails; of mollusca belonging to the genera Orthoceras, Goniatites, Leptæna, Spirifer, Productus, Orthis, Pentamerus, Strophomena; numerous extinct forms of crustacea of great size, called Pterygotus,

Eurypterus, etc., others, called trilobites, as Trinucleus, Asaphus, Calymene, Phacops; and many genera of corals, as Heliolites, Favosites, Calceola; and crinoids, as Actinocrinus, Platycrinus, Pentremites. The plants of this series are chiefly cryptogams, Ferns, Lycopodiaceæ, and Calamites. Graptolites also are characteristic of Palæozoic strata.

LAURENTIAN.

LEWISIAN[1] OR FUNDAMENTAL GNEISS. (Murchison.)

The term Laurentian was given by Sir William Logan to a series of highly contorted gneissic rocks which occur in Canada, in the country drained by the St. Lawrence, and constitute the oldest known sedimentary rocks in the world. Their thickness is estimated at 30,000 feet. Zones of altered limestone included in the series have yielded traces of foraminiferal structure, and the name *Eozoon Canadense* has been applied by Dr. J. W. Dawson to this the oldest evidence of life yet discovered.[2]

The existence of Laurentian rocks in England and Wales, or of English rocks equivalent to the oldest rocks of America, has not been definitely determined; nor is it probable that, in comparing the rocks of these two countries, we can ever do more than state that certain series of strata are homotaxeous, or in other words that they occupy the same relative position in regard to the succession of life in the two areas. The Laurentian rocks, where developed in North Britain, are unconformably overlaid by the Cambrian rocks.

In certain localities in England and Wales there is

[1] This term was taken from the island of Lewis, the largest of the Hebrides, where the rocks were first described by Murchison.

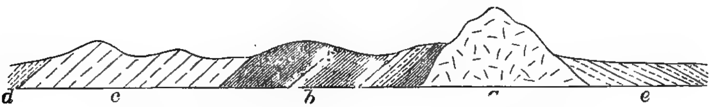
[2] The occurrence of Graphite in these rocks is considered as evidence of a yet earlier vegetation having existed.

evidence of the presence of rocks of Pre-Cambrian age, and therefore it is well to mention some of the opinions that have been expressed concerning them.

England.—Dr. Holl has stated his opinion that the gneissic rocks of Malvern may agree in point of age with the Laurentian series of Canada—that they are the relics of an old Pre-Cambrian continent. Murchison however considered them to be metamorphosed Cambrian strata.

FIG. 1.—*General Section of Malvern.*

(Prof. J. Phillips.)



e. Poikilitic. *c.* Silurian.
d. Old Red Sandstone. *b.* Cambrian.
a. Gneiss (Laurentian ?).

The oldest rocks of Charnwood Forest may in the opinion of both Prof. Ansted and Dr. Holl belong to the Laurentian series. These rocks according to the former geologist (speaking generally) include imperfect and true slates and claystones passing into claystone porphyry and hornblendic porphyry, and so into granitic gneiss, granite and syenite. The slates are quarried for roofing purposes near Swithland. In Charnwood Forest, at Whittle Hill, whetstones are obtained called Whittle Hill Hones, which are said to be among the best substitutes for the Turkey oilstone.

There is a rock too at the Abberley Hills which the Rev. W. S. Symonds has suggested may be of Laurentian age.

Wales.—Some of the crystalline rocks of Anglesea, Holyhead, and the adjacent parts of Caernarvonshire; also the syenitic rocks of St. David's, are regarded as of Pre-Cambrian age, including (according to Mr. Hicks) some old quartz-conglomerate and dark green shales.

CAMBRIAN.

This term is derived from Cambria, the old name for Wales, and as a group it is equivalent in part to the 'Cumbrian' series of the Lake District.

About the year 1834 the name Cambrian was given by Sedgwick to the great mass of the slaty rocks and limestones in North Wales, which at the time were considered to be older than the Silurian rocks of Murchison.

The subsequent researches of Sedgwick enabled him to fix the boundary line of the Cambrian and Silurian rocks at the base of the May Hill Group, which the further observations of geologists have tended to confirm, as a line well-marked by a physical break. Murchison, however, who had included the Caradoc and Llandeilo beds in his Silurian system, but had misplaced them in his typical section, did not concede these strata to the Cambrian; and finding that his system had no definite base on which to rest, took in from time to time group after group of the underlying series, and had to prove at each step that as yet no break had been found in the series, till at length he got down to the lowest Cambrian.[1]

There is therefore some confusion in the different classifications adopted by geologists, some upholding that of Sedgwick, some (including the officers of the Geological Survey in their publications) adopting that of Murchison; while others again have endeavoured to effect a compromise, and have drawn the line between Cambrian and Silurian about midway in the debateable ground, or in the Lower Silurian.

As the opinions most deserving of consideration differ

[1] See Sedgwick, *Palæozoic Rocks, and Catalogue of Cambrian and Silurian Fossils.* Cambridge. Also T. Sterry Hunt, *History of the Names Cambrian and Silurian*; Professor T. McK. Hughes, *Discussion at Meeting of Geol. Soc.*, December 2, 1874; *Rep. Brit. Assoc.*, 1875.

on this somewhat tender subject of classification, I cannot do better than indicate those of both Sedgwick and Murchison. At the same time, for the sake of convenience, I shall arrange the subject-matter according to that of the former geologist, the results of whose early researches amongst the older Palæozoic rocks of North Wales have been shown to be in all essential points correct, but have scarcely been adequately acknowledged.

It is perhaps needless to observe that the names Cambrian and Silurian are mere terms of convenience in classification: one name might indeed be applied to the whole series of rocks, but as we have no reason to doubt that the whole history of the earth was a series of regular changes, so the terms of classification, dividing the history into chapters and paragraphs, are useful divisions that assist the memory and mark out the leading modifications that have taken place over any given area. The divisions between Cambrian and Silurian strata mark no great change in the life history, and yet the classification now adopted is convenient as marking the greatest physical break yet noticed in the series in England and Wales.

The following Table shows the classification of the strata:—

Upper Cambrian (Sedgwick)	Caradoc Beds Llandeilo Beds Arenig or Skiddaw Group.	Bala and Lower Coniston Group	Lower Silurian (Murchison).
Middle Cambrian (Sedgwick)	Tremadoc Beds Lingula Flags	Dolgelly Beds Ffestiniog Beds Maentwrog Beds	Upper Cambrian (some authors): Primordial Silurian (Murchison).
Lower Cambrian (Sedgwick)	Menevian Beds Harlech, Longmynd, Bangor and Llanberis Beds	Longmynd group	Cambrian (Murchison).

The total maximum thickness of the Cambrian strata is estimated at upwards of 30,000 feet in Wales, and at about 20,000 feet in the Lake district. But it must be remembered that owing to the disturbances and changes the beds have undergone, such estimates are very hypothetical.

The Cambrian rocks have, on the whole, been formed in shallow seas, but there are some evidences of tolerably deep water.

LOWER CAMBRIAN.

The Lower Cambrian rocks are often subdivided geographically, or according to the several tracts over which they are exposed. Two well-marked groups are, however, now established:—

Menevian Group.
Longmynd, or Harlech Group.

LONGMYND, OR HARLECH GROUP.

The rocks of this group consist of a series of grey, purple, and red flaggy sandstones, conglomerates and shaly beds, having a thickness estimated at 4,000 feet in South Wales, and supposed to be over 8,000 feet in North Wales. Remains of Sponges, Annelids, Pteropods, Polyzoa, Brachiopods, such as *Lingulella* and *Obolella*; also of Entomostraca, and Trilobites of the genera *Conocoryphe*, *Paradoxides*, *Microdiscus* and *Plutonia*, have been determined in these strata, mainly through the researches of Mr. Hicks.

These indicate the marine origin of the strata in which they occur. Professor Ramsay has suggested that some of the red or purple beds which are unfossiliferous, may have been deposited in inland waters, or lacustrine areas subject to occasional influxes of the sea.

Longmynd Rocks. (Sedgwick.)

GWASTADEN (BRECON) ROCKS. (Murchison, 1834.)
'BOTTOM ROCKS.'

These rocks, so named from the Longmynd hills in Shropshire, consist of green and purple grits, conglomerates and slates. They are developed at the Longmynd and in the neighbourhood of Shrewsbury, where they are overlaid conformably by the Lingula flags. Their thickness has been estimated at 8,000 feet.

The beds contain Annelid burrows, belonging to two species, according to Mr. Salter, who named them *Arenicolites didymus* and *A. sparsus*.

Harlech Grits. (Sedgwick.)

BARMOUTH SANDSTONES.

A large tract of ground between Barmouth and Harlech, extending eastwards to Craig-y-Penmaen in Merionethshire, is composed of greenish grits, interstratified here and there with green and purple slates. The series is stated by Professor Ramsay to be more than 6,000 feet in thickness. The beds are pierced by dykes of igneous rock.

Evidence of sun cracks and rain-drops has been detected on the surfaces of some of the beds.

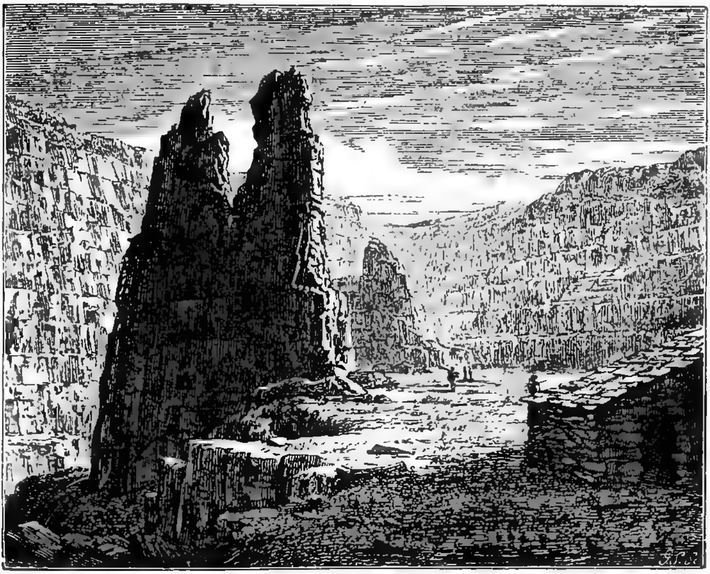
Llanberis Grits and Slates. (Sedgwick.)

This series includes the famous slates of Penrhyn and Llanberis: it comprises the altered purple and green slaty, arenaceous, and conglomeratic beds west and south-west of Bangor; together with the purple and green slates, and grits on the banks of the Ogwen around Bethesda, the lakes of Llanberis, &c. It attains a thickness of about 3,000 feet. (Ramsay.)

The beds contain some igneous dykes, while the cleavage is very intense and distinct from the bedding.

The large slate quarry of Penrhyn is probably familiar to all visitors to North Wales. The summit of the quarry is about 500 feet above the base, and the slates are worked out in terraces, each about 40 feet in height.

FIG. 2.—*Penrhyn Slate Quarry.*
(From a photograph.)



The beds have yielded no fossils save some burrows of marine worms termed *Chondrites.*

The green banding of the slates, and the production of the large uniform masses of green, are considered by Mr. Maw to be not only due to independent causes, but probably to have occurred at different times. The ordinary form of variegation of the slates consists of mechanically formed nuclei

concentrically environed by pale green slate, the bleaching of which has been due to the abstraction of the greater part of the colouring oxides of iron. Mr. Maw has pointed out that this banding and blotching of the slate was formed before the slate was cleaved, and some of the green slate was converted from the purple at the time of the intrusion of the greenstone dykes.

Caernarvonshire.—The Lleyn district (the promontory that separates Caernarvon Bay from Cardigan Bay) contains rocks believed to be of Lower Cambrian age. These are the metamorphosed rocks or schists on the south side of Caernarvon Bay, including Bardsey Island and the coast from Bardsey Sound to Porth Nevin. The age of these rocks has, however, been much questioned.

St. David's.—The grey and purple slates, grits and conglomerates associated with many igneous rocks which are developed on the north side of St. Bride's Bay in Pembrokeshire are of Lower Cambrian age, and comprise a series more than 4,000 feet in thickness. Mr. Hicks has discovered a rich fauna in these rocks, comprising many species of Trilobites, Brachiopods, &c., including species of *Plutonia*, *Conocoryphe*, *Paradoxides*, and *Lingulella*. The cathedral of St. David's is in some parts built of Cambrian sandstone.

Anglesea.—The micaceous and chloritic schists, the gneissic rocks, grits and quartz-rock which constitute the greater portion of Anglesea, are believed to be of Lower Cambrian age, if not older. They are traversed by igneous dykes, and associated with bosses and veins of granite. The exact age of some of the strata on parts of the north coast of the island is by no means certain.

Holyhead Island and the North and South Stack islets are composed of Cambrian grits and schists, showing very violent contortions.

Leicestershire.—The gritty, conglomeratic, and slaty

rocks associated with syenite, and some other igneous rocks, that are exposed in the district of Charnwood Forest, may be of Cambrian age. Many of the rocks are highly metamorphosed, and so gradual has the change been, that the igneous and stratified rocks pass one into the other. (See p. 24.)

MENEVIAN BEDS.

The term Menevian, from the old Roman name of St. David's, was proposed by Mr. J. W. Salter and Mr. Hicks for a series of black and grey slates and flags with thick beds of sandstone which underlie the true Lingula Flags, and attain a thickness of 500 or 600 feet. They contain many species of trilobites, amongst which the large *Paradoxides Davidis*, sometimes nearly 2 feet in length, is conspicuous. Most of the characteristic fossils are as yet unknown in the beds above. One Cystidean and some Entomostraca make their appearance.

The Menevian beds are developed at St. David's in South Wales, and in the neighbourhood of Maentwrog and Dolgelly in North Wales.

At St. David's the beds are very fossiliferous, and so closely related palæontologically to the Longmynd group that Mr. Hicks (in 1867) proposed to class the two groups together as Lower Cambrian.

MIDDLE CAMBRIAN.

LINGULA FLAGS.

PRIMORDIAL ZONE. (Barrande.)

These beds were first named in consequence of Mr. Davis's discovery in 1845 of *Lingula* (*Lingulella*) *Davisii* in these rocks near Tremadoc. They consist of slaty and shaly beds

with grits and hard sandstones, often much altered. Where well developed they attain a thickness of from 5,000 to 6,000 feet; but half this estimate is sometimes considered sufficient. They pass insensibly into the Lower Cambrian rocks.

A 'pod-shrimp' (*Hymenocaris*) and many Trilobites make their appearance in them.

The quartz-rock ridge of the Stiper Stones is underlaid by black and dark-blue slaty beds with *Lingulæ.*

Many dykes and intrusive bosses of igneous rock penetrate the beds: such may be seen in the Ffestiniog Slate Quarries.

The Lingula beds are well developed in Merionethshire, ranging from the mouth of the Barmouth estuary to the north-east, and then circling round the Cambrian grits by Ffestiniog they pass out to sea on the south side of Traeth Bach.

They lie on the west side of the Longmynd; and may be studied at St. David's in South Wales, where they rest conformably upon the Menevian beds, and attain a thickness estimated by Mr. Hicks at 2,000 feet.

The gold lode of Dol-frwynog occurs in a talcose schist associated with igneous rocks on the horizon of the Lingula Flags.

In the maps of the Geological Survey, all the strata (excepting the Igneous rocks) from the Lingula Flags to the Lower Llandovery strata have received one colour; for though an order of succession can be made out by help of fossils, yet practically most of the formations pass so gradually into each other that it is impossible to define their limits on the map. (Ramsay.)

Maentwrog or Lower Lingula Flags.

OLENUS BEDS.

This name was proposed by Mr. T. Belt in 1867 for the slates and flags with bands of sandstone, characterized by typical forms of *Olenus*, and which are exhibited in great per-

fection at and around the village of Maentwrog. The Maentwrog group is specially characterized by its dark blue jointed ferruginous slates. It attains a thickness of about 2,500 feet. *Agnostus nodosus* and *A. pisiformis* occur with two or three species of Olenus. Phyllopoda make their appearance. The slates are sometimes worked for economic purposes. The gold-mines of Hafod-y-morfa, Cefn-deuddwr, have been opened in these beds. Ores of copper, lead, and zinc occur in small quantities.

The Maentwrog beds extend from a little above Barmouth to Llanelltyd. They are well-developed in the Waterfall valley and in the valley running from Tafarn-helig to Caen-y-coed.

They are seen at St. David's in South Wales.

Ffestiniog or Middle Lingula Flags.

Mr. Belt proposed (1867) to restrict the name of Ffestiniog group to the hard sandy and micaceous flags containing *Lingulella Davisii*, and *Hymenocaris vermicauda*, which lie conformably upon the Maentwrog beds. This group is about 2,000 feet in thickness. Good building-stones and flags are worked in it; and copper-ore has been obtained at Glasdir.

The river Mawddach cuts through the whole of the beds between Rhiwfelyn and Hafod-fraith. They cross the Wnion near Glyn Maldon, and then by Gwern-y-barcud and Tyn-y-craig, range to Coed-y-garth, and into the estuary of the Mawddach. They occur at Ramsey Island, near St. David's.

Dolgelly or Upper Lingula Flags.

The term Dolgelly group was proposed by Mr. Belt (1867) for the soft blue and black slates of the neighbourhood of Dolgelly. They are characterized by a small species of *Orthis* and by *Parabolina (Olenus) spinulosa*.

Mr. Belt states that the slates in the Upper Dolgelly beds give a black streak, and that with the exception of a thin layer of black slate in the Ffestiniog group, there are no other beds in the Dolgelly district so characterised.

The fossils in the Dolgelly group include many Trilobites, such as *Conocoryphe*, *Sphærophthalmus*, *Agnostus*, &c. A few molluscs also occur.

The beds are developed at Dolgelly and near Portmadoc. In South Wales the series comprises bluish and grey flags. Their thickness is estimated at 600 feet.

TREMADOC SLATES.

This formation, so called by Sedgwick in 1846 from the town of Tremadoc in Caernarvonshire, consists of blue and grey slates, flags, and sandstones, having a thickness of about 2,000 feet. They rest conformably upon the Lingula Flags.

Their occurrence was unknown out of Merionethshire until, in 1866, Messrs. Salter and Hicks indicated their presence near St. David's.

Many Trilobites are found belonging to the genera *Ogygia*, *Asaphus*, *Conocoryphe*, *Olenus*, &c. In this formation Cephalopoda first make their appearance, such as *Orthoceras* and *Cyrtoceras*; Hydrozoa, Crinoids, Asteroids, and Lamellibranchs appear. *Lingulella Davisii* is met with, also *Conularia*.

Mr. Hicks has made three divisions in the Tremadoc slates —the lower beds, consisting of grey flaggy sandstones, about 1,000 feet in thickness, occur at Tremanhire, Ramsey Island, and Llanveran, near St. David's. The middle division consists of dark earthy slates, and the upper division of iron-stained slates and flags: these have a united thickness of about 1,000 feet, and occur at Portmadoc and Dolgelly.

The upper division he has (in a table of Strata, 1873) placed in the lower part of the Arenig group.

Certain light green micaceous shales occurring at Cressage, near the Wrekin, have been identified with the Tremadoc rocks.

Rocks considered to be on the horizon of the Tremadoc Beds or Upper Lingula Flags occur at Malvern.

Hollybush Sandstone.

This consists of greenish grey or brownish sandstone, with quartz-conglomerate at base, resting unconformably upon the gneiss of Malvern, and attaining a thickness of from 200 to 600 feet (see fig. 1, p. 24). Dr. Holl has found in it Annelids (*Trachyderma antiquissima*), and some Brachiopoda of the genera *Lingula* and *Obolella.*

The Hollybush Sandstone may be studied on Raggedstone Hill, overlooking the Hollybush valley, Malvern. Mr. Hicks places it on the horizon of the Ffestiniog beds.

Malvern Shales.

Above the Hollybush Sandstone comes the 'Black Shale' of Malvern. This deposit consists of thinly laminated black carbonaceous and pale greenish shale, from 500 to 1,000 feet in thickness, enclosing some bands of trap, composed of felspar and hornblende. The eruptive rock is an ancient lava, consolidated for the most part underground, or under the sea. The great deposit of shale must have been formed in calmer and probably deeper water than the Hollybush Sandstone, there having been doubtless a continual subsidence of the sea-bed interrupted by occasional volcanic outbursts. (J. Phillips.)

The Black Shale has yielded among the Trilobites, species of *Conocoryphe*, *Olenus*, *Sphærophthalmus*, *Agnostus*; and among the Brachiopods, *Lingula* and *Obolella.*

The uppermost part of the Malvern Shale is called the Dictyonema Shales by Dr. Holl on account of its being characterized by the presence of *D. sociale.* He states that this Polyzoon occurs in North Wales above the Lingula Flags. Mr. Hicks places the beds with the Dolgelly rocks.

UPPER CAMBRIAN (Sedgwick).

LOWER SILURIAN (Murchison and Geol. Survey).

ARENIG ROCKS. (Sedgwick.)

LOWER LLANDEILO. (Murchison.)

The Arenig mountains of Merionethshire give their name to this formation, which consists of shales, slates, and sandstones.

The quartzose rocks called Stiper Stones in Shropshire belong to this series: they extend for ten miles, from Shrewsbury to near Bishop's Castle, and were by Murchison originally considered as the base of the Silurian System (1833-4). The thickness of the Arenig Rocks is about 1,000 feet.

The fossils comprise *Obolella*, *Ogygia*, *Calymene*, and many species of Graptolites: the species were considered by Salter to be distinct from those of the overlying Llandeilo Flags, but at the same time he regarded the Tremadoc Group as the natural termination of the Middle Cambrian, and the Arenig Group as the true base of the Upper Cambrian or Cambro-Silurian.

The Stiper Stones consist of a thick band of siliceous sandstones, in parts veined, altered and fractured, and occasionally passing into crystalline quartz-rock. They constitute the natural base of the Llandeilo rocks of the Shelve and Corndon district. (Murchison.)

The Arenig Rocks are well developed at Shelve, in the Arenig Mountains, and at St. David's. At this last-named locality Mr. Hicks describes the series as consisting for the most part of black slates, attaining a thickness of nearly 4,000 feet, and affording evidence of being deposited in deep sea.

Mr. Hicks has there divided the series into three groups:—

Upper Arenig, consisting of fine black shales and slates about 1,500 feet in thickness, and yielding many species of Trilobites, Gasteropods, Brachiopods, and Lamellibranchs.

Middle Arenig, consisting of slates, flags, and bands of grit, about 1,500 feet in thickness, and yielding Trilobites and a few species of Graptolites.

Lower Arenig, consisting of fine black shales and slates attaining a thickness of about 1,000 feet, and resting conformably upon the Tremadoc group. Amongst the fossils are many species of Graptolites, Trilobites, &c.

SKIDDAW SLATES.

The slates of Skiddaw are of a dark bluish or black colour, and contain flaggy beds with veins of quartz, also chiastolite slate.

The slate is generally of very uniform texture, soft, fine-grained, and very fissile, and has been employed in the vicinity of Keswick and Hesket Newmarket for roofing houses; but for this use it is not very suitable, as it easily perishes in the atmosphere. In consequence of its want of durability, the mountains of this slate have smoother contours, more uniform slopes, and a more verdant surface than those of the following series (Green Slates and Porphyries). (Phillips.)

The Skiddaw Slates attain a thickness of about 7,000 feet, and are considered to represent the Arenig group. They constitute the lowest beds of the Cambrian (or Cumbrian) series seen in the Lake District.

The peculiar 'cone in cone' structure is often met with in these rocks.

Ores of Iron, Copper, Cobalt, and Lead occur in places. Slate-pencils have been largely manufactured near Shap.

The beds are developed near Egremont, Cockermouth, Crummock Lake, Black Coomb, &c., and they occur over a large area in the Isle of Man.

The Graptolites form the most remarkable fossils of the Skiddaw Slates: these include the genera *Dichograpsus*, *Tetragrapsus*, and *Phyllograpsus*.

Some Trilobites occur, also *Lingula brevis*, *Palæochorda major*, and Annelide burrows.

LLANDEILO FLAGS.

TRILOBITE SCHISTS. (Murchison, 1834.)
BUILTH FLAGS.

The name is taken from the town of Llandeilo in Caermarthenshire, where the rocks were first described by Murchison.

They consist of bluish-grey and black micaceous and calcareous flags, with black shales or slates at the base. Associated with them are many igneous rocks. The total thickness of the series is estimated at 3,300 to 4,000 feet, including sometimes 2,500 feet of lavas.

The Llandeilo Flags near Builth rise in a boss in the midst of the Silurian rocks, which lie unconformably upon them.

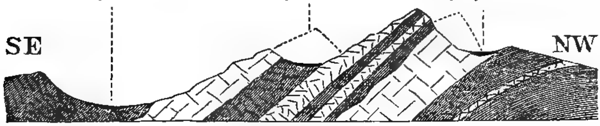
Cader Idris is formed of the Llandeilo beds with their included felspathic ashes, &c.

The beds are well developed in Shropshire, in the Shelve district, &c., and are probably represented in Anglesea.

The fossils include *Asaphus tyrannus*, *Ogygia Buchii*, *Calymene*, *Leptœna*, *Lingula*, *Orthoceras*.

FIG. 3.—*Section of Cader Idris.*

(Reversed and reduced from the Geological Survey Sections.)[1]



1. Slate and Shale. 2. Felspathic Trap. 3. Slates with Felspathic Ashes. 4. Amygdaloidal Greenstone. 5. Felspathic Ashes with two bands of Slate. 6. Greenstone. 7. Slate. 8. Felspathic Trap. 9. Felspathic and Calcareous Ashes, and Slates.

At St. David's, and throughout Pembrokeshire, these beds, according to Mr. Hicks, may be divided into three groups:—

Upper Llandeilo—slates and flags with interbedded igneous rocks. 2,000 feet.

Middle Llandeilo—Calcareous beds and black slates. 1,000 feet.

Lower Llandeilo—Black slates, with interbedded felspathic ashes and tuffs. 500 to 7,000 feet.

BORROWDALE SERIES (Harkness and Nicholson), or **GREEN SLATES AND PORPHYRIES** (Sedgwick).

CHLORITIC SLATE AND PORPHYRY.

In Cumberland and Westmoreland, overlying the Skiddaw Slates, comes a great thickness of igneous rocks, called the

[1] This section is borrowed from Mackintosh's *Scenery of England and Wales*, p. 150. The scale is one inch to a mile, and the dotted lines represent Cyfrwy, or the Saddle, to the west of Llyn-y-Gader, and the steep cliff behind Llyn Cae or Cau. (Mackintosh.)

Green Slates and Porphyries, capped by the Coniston Limestone. The series consists of slates alternating with porphyries and felspathic ashes, and conformably overlying the Skiddaw Slates. Mr. Aveline states that, as a whole, the beds consist of lavas and consolidated or altered ashes and breccias, which have been ejected from volcanic vents, and vary in lithological character from thick-bedded coarse breccia to an ash so fine in texture that, when well cleaved, it yields good slates. Hence the name 'Green Slates and Porphyries,'—the porphyries being the lavas or altered ashes, in which a porphyritic structure has been developed. The thickness is estimated at from 7,000 to 10,000 feet.

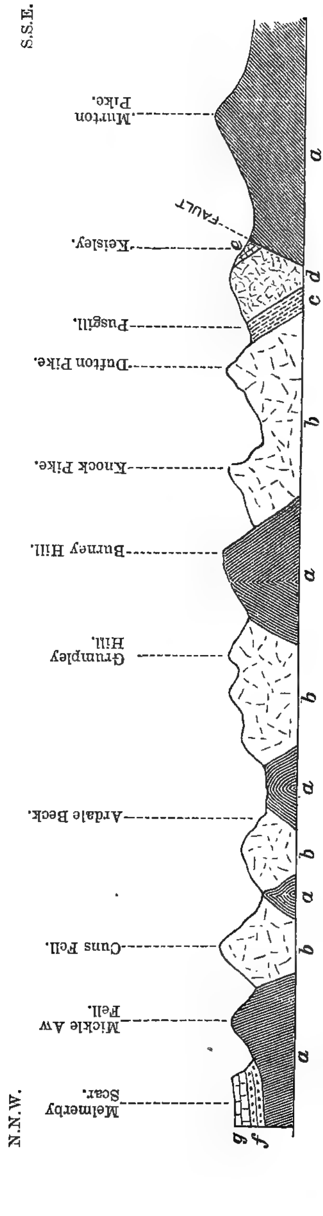
Dr. Nicholson states that the lower portion of the group is not known to contain any organic remains, and may possibly be of the age of the Upper Llandeilo. The upper portion, however, contains a band of fossiliferous shales, with characteristic Bala fossils; and the group, he considers, may be partly of Upper Llandeilo, and partly of Lower Bala age. Fossils have been obtained by Professor Harkness and Dr. Nicholson in the shales of Dufton, Swindale, and Pusgill—sometimes called the Dufton Shales, &c., after these localities.[1] The fossils include two species of Corals, stems of Crinoids, Brachiopods, Lamellibranchs, *Holopea*, *Bellerophon*, *Orthoceras*; and Crustacea, such as *Agnostus*, *Calymene Blumenbachii*, *Homalonotus bisulcatus*, &c.

The lowest rock belonging to this system is a red, argillaceous, fissile stratum, characterized universally by its mottled colours, abundant along the eastern shores of Derwentwater, especially about Barrow and in St. John's Vale; in both localities resting upon the Skiddaw slate. It is distinctly stratified, dipping to the south-east, and is of considerable thickness. It passes upwards into the Green slate. The

[1] It is not clear, so Professor Hughes tells me, that these fossiliferous shales belong to the Green Slates and Porphyries.

Fig. 4.—*Section from Mickle Aw Fell to Murton Pike, Lake District.*

(Prof. R. Harkness.)



g. Carboniferous Rocks. f. Upper Old Red Sandstone. e. Bala or Coniston Limestone. d. Upper Greenstones, Porphyries, and Ashes.

c. Fossiliferous Flaggy Shales. b. Greenstones, Ashes, and Porphyries. a. Skiddaw Slates.

Bowder stone is a peculiar metamorphosed slate. Green slates are best developed on the south-eastern slopes, and occupy a long range of mountains parallel to the Skiddaw slates, and in those highly picturesque and romantic valleys wherein the lakes of Ulleswater, Haweswater, Thirlmere, and Wastwater spread their beautiful waters. (Phillips.)

FIG. 5.—*The Gorge of Borrowdale between the Bowder Stone and Castle Crag.*

(Looking south.[1])

The occurrence of the Borrowdale series in the Isle of Man has been pointed out by Professor Harkness and Dr. Nicholson.

In consequence of the superior hardness of the rock, and its frequent association with igneous products, the Green slate mountains assume bolder forms, present more lofty and rugged peaks, and more inaccessible precipices, than the softer slates of Skiddaw. (Phillips.)

[1] This woodcut is borrowed from Mackintosh's *Scenery of England and Wales*, p. 238.

CARADOC, OR BALA BEDS.

UPPER CARADOC. (J. Phillips, 1842.)

The Caradoc Sandstone was first noticed by Murchison in 1833, and in 1834 he described the strata under the name of Horderley and May Hill Sandstone. Subsequently, in the Silurian System (1839), they were called Caradoc Sandstone from the circumstance of their being typically developed in the neighbourhood of Caer Caradoc. (Ramsay.)

The term Bala Beds was given by Sedgwick.

The typical Bala or Caradoc beds lie in the Bala district, between Dinas-Mowddwy, Bettws-gwerful-goch, and Bettws-y-Coed. They consist of black and blue slates, and grey and brown arenaceous beds; the Bala limestone, generally very impure, lying about the middle, and averaging from 20 to 30 feet in thickness. Between the limestone and the lower traps of the Arenigs and Llyn Conwy, two, and sometimes three thin and imperfect beds of volcanic ashes represent the whole of the vast volcanic accumulations of Moel Hebog, Snowdon, and Carnedd Llewelyn. The middle part of the Bala beds, including the limestone, is most fossiliferous, the black slates below, and the slaty and sandy interstratifications above, being comparatively barren. (Ramsay.)

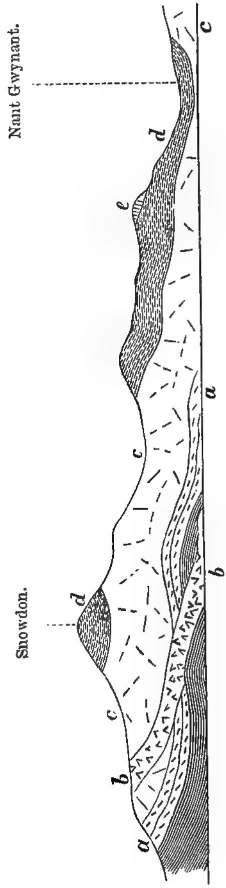
The thickness of the series is estimated at from 10,000 to 12,000 feet. Murchison states that the limestones and sandstones in North Wales do not present a thickness of more than 1,050 feet, while those of Shropshire attain about 4,000 feet.

The beds are found in Anglesea, but the best localities are Caradoc, Horderley (shelly sandstones), Norbury, Bala, and Snowdon. The Meifod beds may also be included. North-west of Bala, the Rhiwlas limestone—a grey limestone, 30 to 40 feet thick, contains many fossils.

North of Moel-Siabod (according to Professor Ramsay) the Bala beds assume a markedly different character from that which they possess between Dinas-Mowddwy and

FIG. 6.—*Section of Snowdon.*

(Prof. A. C. Ramsay.)



e. Columnar Felspathic Rock. *d.* Volcanic Ashes, sometimes calcareous and fossiliferous=Bala Limestone.
c. Felspathic Porphyry. *b.* Greenstone (intrusive). *a* Fossiliferous Grits overlying slaty beds.

Dolwyddelan, for they contain a much greater number of interbedded felstones and volcanic ashes, which range northward to Conway, and from thence south-west along the higher

Caernarvonshire mountains. Carnedd-Llewelyn, Carnedd-Dafydd, Y-Glyder-fawr, Snowdon, and Moel-Hebog are the chief mountains in this, the wildest and grandest part of North Wales. And these, like the ranges of Cader Idris, the Arans, and Moelwyn, consist in a great degree of volcanic products. These volcanic rocks belong to two sections of the [Cambrian] period, for the felstone porphyries and felspathic ashes, and perhaps even the intrusive greenstones of Merionethshire, were formed during the deposition of the Llandeilo strata, while the same species of thick-bedded traps and ashes on Snowdon and the surrounding mountains are high in the Bala or Caradoc series. In both cases they form the highest mountain ranges in Wales, not from upheavals caused by the *intrusion* of igneous masses in special areas, but simply from the circumstance that long after their formation, while lying deep below thousands of feet of newer strata, the whole of the rocks of the area have been disturbed; and the hard igneous masses now rise so high because they have better withstood degradation than the slaty rocks with which they are interbedded. The ranges formed of the lower porphyries, &c., of Cader Idris, Aran Mowddwy, Arenig, and Moelwyn, lie midway up in the strata of the great Merionethshire anticlinal, while the peaks of the still higher range of Moel-Hebog, Snowdon, and Carnedd-Llewelyn actually lie in the middle of a basin. The whole form but minor parts of an old mountain system, of which Wales is only a fragment. (Ramsay.)

In Shropshire the 'Caradoc sandstone' admits of the following divisions, according to Messrs. Salter and Aveline:—

5. Thin-bedded sandy shales full of *Trinucleus concentricus*. (Trinucleus shales.)

4. Very fossiliferous brown and yellow sandstones.

3. Thick beds of freestone (Horderley flags).

2. Coarse yellow sandstone, in places a conglomerate, and containing calcareous bands. (Hoar Edge grits.)

1. Sandy and argillaceous shales, sometimes fossiliferous.

The fauna of these beds is particularly rich in Trilobites and Brachiopods, amongst which may be mentioned *Trinucleus concentricus*, *Orthis* (*Strophomena*) *grandis*, *Orthis vespertilio*. Two genera of starfish, *Protaster* and *Palœaster*, are found at Bala.

In the Caradoc sandstone, remains of fossils are often so abundant as to render some of the beds sufficiently calcareous to be burnt for lime: these beds are known to the workmen as 'Jacob's Stones.' (Murchison.)

Some valuable deposits of phosphate of lime (phosphorite) have been discovered on the top of the Bala Limestone in North Wales. Beds of jasper occur at Dinas-Mowddwy, and other places.[1]

Welsh oilstone is obtained from the vicinity of Llyn Idwal, Snowdon, and sometimes called Idwal stone. From Snowdon the 'Cutler's green stone' is also obtained.

The Gore stone, which occurs near Kington in Radnorshire, is considered to be an altered rock of Caradoc age.

Hirnant Limestone. (Sedgwick.)

This limestone is locally developed in the valley of Hirnant, south-east of Bala, and in a tortuous tract between Bala and Dinas-Mowddwy. It is described as a black pisolitic and fossiliferous limestone, containing species of Orthis (*O. Hirnantensis*, *O. sagittifera*, &c.), *Arca* and *Modiolopsis*.

It occurs locally near the junction of the Bala Beds and the Upper Llandovery, and was considered of Upper Bala age by Sedgwick.

[1] The Dinas sand is used for lining copper-furnaces.

Mevagissey.—The grey quartzites of Veryan Bay, first described by Murchison, have been considered by Sedgwick and M'Coy to be of Upper Bala age, the fossils from Carn Goran (Gorran Haven) being *Orthis calligramma, O. alternata, Calymene brevicapitata, C. parvifrons, Homalonotus bisulcatus*, &c. They were first made known by the collections of Mr. Peach. The rocks at Bolt Head, South Devon, are metamorphosed Devonian slates.

LOWER CONISTON GROUP.

CONISTON LIMESTONE. (Sedgwick.)

This group consists in its lower division of bluish-grey limestone and calcareous slate, and above of flagstone and slate (Ash Gill or Lower Coniston Flags), generally calcareous, having a total average thickness of about 300 feet.

It is placed on the horizon of the Bala beds, but does not contain so great a development of limestone nor so many fossils as do those rocks. The beds rest conformably upon the Green Slates and Porphyries.

The Coniston Limestone stretches from the estuary of the Duddon to near Ambleside and Wastdale Crag. It occurs also in the Furness district, where the formation was called Ireleth limestone by Sedgwick; and it may be studied on the western side of Troutbeck.

The Coniston Limestone is rich in fossil Corals, Brachiopods (*Leptæna, Orthis, Strophomena*), species of Orthoceras, and Crustacea (*Agnostus, Calymene, Cheirurus, Illænus*).

The upper portion of the series, consisting of slaty beds, is termed Trinucleus and Strophomena shales by Professor Hughes, from the occurrence in them of these fossils.

CHAPTER II.

SILURIAN.

UPPER SILURIAN. (Murchison and Geol. Survey.)

THE term Silurian System, with which the name of Murchison will ever be connected, was given in 1835 from the country of the ancient Britons known as Silures; and it is, for the reason stated in the previous chapter, here confined to the rocks between the Caradoc or Bala beds and the Old Red Sandstone. The beds rest unconformably upon the Cambrian rocks.

The total thickness of the system may be as much as 6,000 feet, but it is by no means easy to give the thickness with accuracy: it varies from 3,000 to 6,000 feet, for the beds themselves are subject to much local change. Sedgwick has observed that where the Woolhope limestone is well developed, as at Presteign, there the Wenlock limestone is very feebly represented. At Wenlock the limestone forms a grand terrace, but the Aymestry limestone has almost vanished. At Leintwardine the Aymestry limestone is a grand rock, and the Wenlock limestone is but poorly developed.

The organic remains of the Silurian rocks indicate their marine origin, and show that the beds were deposited in a *continuously but slowly subsiding area*, and in water never of very great depth. Some of the limestones are the remains of old coral reefs.

The following Table exhibits the main divisions of the Silurian strata:—

Wales		Lake District
Ledbury Shales (Passage Beds).		
Downton Sandstones.		
Upper Ludlow.		Kirkby Moor Flags.
Aymestry Limestone.		
Lower Ludlow.		Bannisdale Slates.
Wenlock Limestone and Shale	Wenlock Beds	Coniston Grits and Flags.
Woolhope Limestone and Shale		Stockdale Slates.
Denbighshire Grits.		
Tarannon Shale.		
May Hill Group.		

MAY HILL GROUP.

LOWER LLANDOVERY ROCKS.

These rocks, which consist of hard grey grits and conglomerates, with beds of slate and shale, were formerly included among the Caradoc Beds.

Professor Ramsay remarks that in mineral character these beds so strongly resemble the Upper Llandovery rocks, that up to 1856 no geologist had been able to distinguish between them. They attain a thickness of from 600 to 1,000 feet, or even 1,500 feet. The stratigraphical evidence, as Professor Hughes tells me, shows that Llandovery Rocks rest unconformably on beds older than any Llandovery Rocks, but it does not seem to be shown by reference to any localities that Upper Llandovery is unconformable to Lower Llandovery.

Casts of *Pentamerus oblongus* are common in this rock, near Wrexham and elsewhere.

Near Builth and Llandovery the beds appear to be most fossiliferous. But, I am informed by Professor Hughes, that there is no trustworthy list showing what fossils are peculiar to Upper and what to Lower Llandovery; and while palæontologists cannot separate the fossils of the two formations into well marked groups, stratigraphical geologists confess the difficulty of separating them in the field. Therefore he would

regard them as forming one distinct group, the May Hill Group, and include with them the Tarannon Shale, in part.

The Lower Llandovery strata appear south-east of Bala Lake, and are developed over a great part of South Wales, near Rhayader, Garth, &c. The junction with the Upper Llandovery beds is seen near Noeth Grug, north-east of Llandovery. These rocks extend over a good deal of country on the borders of Cardigan Bay, between Aberystwith and Cardigan, and are exposed at Haverfordwest.

UPPER LLANDOVERY ROCKS OR MAY HILL SANDSTONE.

PENTAMERUS BEDS. (*P. oblongus* zone.)

These rocks consist of grey and yellowish sandstones and conglomerate, attaining a thickness of about 800 feet. Sometimes a calcareous band is met with: as for instance the Norbury Limestone and Hollies Limestone.

The Upper Llandovery Beds of Murchison were at first considered to be the highest beds of the Caradoc Sandstone, and conformable with it: their true position was determined by Sedgwick.

In Shropshire, according to Messrs. Salter and Aveline, the 'Pentamerus beds' comprise :—

Purple shales, 200 to 400 feet thick.
Thin limestone bands, interstratified with ochreous sandstone and argillaceous shales (Pentamerus beds proper).
Conglomerates and sandstones.

In North Wales the Upper Llandovery rocks are absent, and the Bala beds, as far north as the ground 6 miles south-east of Bala Lake, are overlaid by a long strip of grit probably belonging to Lower Llandovery strata, and this is overlaid by pale-grey, purple, and green Tarannon shales.

The May Hill Sandstone yields species of corals, *Favosites*, *Heliolites*, and *Petraia*; Annelides, Trilobites, and Mollusca, the Brachiopoda being most abundant. Amongst the species are *Pentamerus lens*, *P. oblongus*, *Atrypa reticularis*, *Strophomena compressa*, *Bellerophon trilobatus*, *Encrinurus punctatus*, and *Petraia subduplicata*.

In South Wales these beds first appear in Marloes Bay, and, at intervals, range across Pembrokeshire; but further north and east they disappear for a space, being overlapped by the Old Red Sandstone. They re-appear south of Llandeilo, and varying from a few feet to 1,000 feet in thickness, they range north-east in a narrow strip through parts of Caermarthenshire, Breconshire, and Radnorshire, lying indifferently upon Lower Llandovery, Caradoc, or Llandeilo Beds. Near Builth, only a few feet thick, they rest quite unconformably upon the Llandeilo Flags and their associated igneous rocks. They are also found near Presteign, where they are locally called 'Corton grit.' They occur at Nash Scar, and in Shropshire they lie very unconformably on the Caradoc Sandstone, between the neighbourhood of Cardington and Coalbrook Dale. In the Longmynd country they also lie quite unconformably in the form of a calcareous conglomerate on Cambrian rocks, and beyond this in Wales they are not known anywhere at the western base of the [Silurian] strata between Radnorshire and the mouth of the Conwy. (Ramsay.)

The Upper Llandovery rocks are developed in the Lower Lickey Hills in Worcestershire, and in Staffordshire; at the Lickey, low heathy hills occur chiefly composed of quartz-rocks, lithologically identical with those masses on the flanks of the Caradoc and Wrekin which have been formed by the fusion of sandstone. (Murchison.)

They occur at May Hill, Shelve, and Tortworth. At Malvern the beds consist of grey and purple laminated sandstones and shales having a thickness of 500 feet, resting

upon grey and purple sandstones and conglomerates about 600 feet in thickness. (Phillips.)

TARANNON SHALE. (Geol. Survey.)

Pale Slates.

These beds comprise smooth pale-blue and greenish-grey slates and shales 1,000 to 1,500 feet in thickness.

They were first mapped by Mr. Aveline. These shales form the lowest part of the Silurian rocks of North Wales, and from beneath the Denbighshire grits they are exposed in a narrow and nearly unbroken line from the mouth of the Conwy to near Builth in Radnorshire, where they are strikingly unconformable to the various underlying members of the Cambrian strata.

In South Wales they rest conformably upon the Upper Llandovery rocks. No fossils have been found in the beds.

STOCKDALE SLATES.

Graptolitic Mudstones. (Harkness and Nicholson.)

The Stockdale slates (which occur in the Lake District) are of a pale colour, passing downwards into black shales with graptolites, and containing calcareous grit and conglomerate.

They are placed on the horizon of the Tarannon Shale.

Amongst the fossils are Graptolites, *Diplograpsus*, *Rastrites*, &c., also *Endoceras*.

Dr. Nicholson states that the beds rest in the Lake District upon the Coniston Limestone, and in the Sedbergh District upon the Trinucleus and Strophomena Shales.

LOWER WENLOCK BEDS.

DENBIGHSHIRE GRITS. (Bowman, 1841, and Sedgwick.)

This formation consists of a series of shales, flagstones, sandstones, and grits, attaining a maximum thickness of at least 3,000 feet. According to Professor Ramsay, they form but a local variety of the Wenlock formation; and apparently, where the grits thin away and disappear, instead of being overlapped by the shale, they rather pass by lithological gradations into strata of a shaly character.

Professor Ramsay observes, that in some areas fossils are absent or very scarce in the grits, a few fragments of Encrinites or of bivalve mollusca alone showing that they are fossiliferous. In many places, however, fossils are plentiful, as near Conway, at Plas Madoc, near Pentre Voelas, Craig-hir, &c. Amongst the fossils may be mentioned *Phacops Downingiæ*, *P. caudatus*, *Calymene Blumenbachii*, *Rhynchonella*, *Strophomena*, *Leptæna*, *Euomphalus*, *Murchisonia*, *Bellerophon*, *Orthoceras*, &c.

The Denbighshire grits succeed the Tarannon shale, and, interstratified with slaty shales, form the base of the Wenlock strata. They run from north to south, in a long sinuous and sometimes broad strip, from the mouth of the Conwy to Melenydd. East of Bala Lake they lie in a trough, from two to four miles wide, and the Tarannon shale and older rocks of the Berwyn hills rise from underneath their eastern boundary. North of the Berwyn hills, between Llangollen and Corwen, the Denbighshire grits, more shaly in character, overlie the Tarannon shales; and in the valley of the Vyrnwy, and eastward by Welshpool and the Long-mountain, and round the older rocks of the Shelve and Corndon country, the sandy character of the base of the Wenlock Shale has entirely disappeared. In Radnorshire, 10 or 12

miles north of Builth, the Denbighshire grits die out, but their equivalents in a more shaly form are believed by Mr. Aveline to strike into South Wales. (Ramsay.)

UPPER CONISTON GROUP.

CONISTON GRITS AND FLAGS. (Sedgwick.)

The Coniston grits and flags consist of hard siliceous sandstone or grit, flags and conglomerate, with thin bands of slate, which are placed on the horizon of the Denbighshire Grits and Flags. The upper part contains, especially, beds of grit or tough sandstone; the lower comprises flaggy beds, or sandy mudstones.

The thickness of this group is estimated by Professor Hughes at between 6,000 and 7,000 feet in the Sedbergh and Howgill districts: Dr. Nicholson considers it may be more in the Lake district proper, but there is no continuous section, and the beds are much disturbed and faulted.

This group is stated by Professor Hughes to rest unconformably upon the Coniston limestone, but Professor Harkness and Dr. Nicholson have failed to detect this, and consider the group to have no exact equivalent in the typical Silurian district in Wales, but to be intercalated as a unique deposit between the Bala Limestone and the Lower Llandovery.

The Coniston Flags yield many species of Graptolites, an *Orthoceras*, worm-tracks, &c.; the Coniston Grits contain fewer fossils, including Graptolites, *Phacops Downingiæ*, *Orthoceras Ludense*, Encrinites, and *Rhynchonella navicula*.

Prof. Harkness mentions that in the vale of Troutbeck the Coniston Flags have been very extensively worked; and at Applethwaite Common they are succeeded by higher strata belonging to the same series, to which Sedgwick gave the name 'Sheerbate Flags.'

WOOLHOPE BEDS.

The term 'Woolhope' is derived from the occurrence of these strata at Woolhope, near Hereford.

The Woolhope Limestone and Shale are regarded as forming a subordinate part of the Wenlock formation. This formation, which rests on the Upper Llandovery rocks, as seen in Shropshire and parts of North Wales, consists of dark grey shale, agreeing, according to Murchison, with the Tarannon shale, and containing subordinate and thin nodular masses of limestone and calcareous sandstone. The limestone is more largely developed in Radnorshire. The formation is rich in Trilobites, Brachiopoda, and also in Cephalopoda: these include *Homalonotus delphinocephalus*, *Illœnus Barriensis*, *Phacops caudatus*; *Spirifer*, *Strophomena*, *Leptœna*, *Atrypa*; *Orthoceras annulatum*, &c.

The Woolhope limestone at Malvern is a rough, impure limestone, with occasional beds of sandstone intercalated, having altogether a thickness of about 150 feet. (Phillips.)

It may be studied north of Crumpend Hill, and near the Wych.

UPPER WENLOCK BEDS.

WENLOCK SHALE. (Murchison.)

This formation consists of shales, with flags and sandstones.

It is the largest and most persistent member of the Wenlock formation, and occurs both below and above the Woolhope limestone,—the latter being absent in many tracts, and in others represented solely by a few small rounded concretions of impure earthy limestone. The shale is well exposed near Coalbrook Dale and the Iron Bridge, and may thence be followed all along the escarpment of Wenlock Edge.

At Malvern, the Wenlock Shale, consisting of dark blue or grey sandy shale with thin bands of limestone-nodules, is estimated by Professor Phillips to have a thickness of 640 feet.

The Wenlock Shale contains several species of *Orthis*, *Leptæna*, and *Rhynchonella*, also *Euomphalus*, *Bellerophon*, *Theca*, and *Orthoceras*. *Encrinurus*, *Calymene*, *Sphærexochus*, and *Phacops*. Crinoids also are not uncommon.

WENLOCK LIMESTONE. (Murchison.)

DUDLEY LIMESTONE.
HAY HEAD OR BARR LIMESTONE. (*Walsall.*)

The Wenlock Limestone consists of thick beds of concretionary or nodular limestone of a light grey colour, containing numerous fossils and separated by beds of shale. It rests conformably upon the Wenlock Shale.

In parts of Wenlock Edge the rock is more crystalline; and where varied colours prevail, the matrix being charged with Encrinites and corals, it forms a pretty marble, though the slabs are of no great dimensions. (Murchison.)

Some of the beds consisting of impure earthy limestone and shale, contain large concretionary masses of good limestone, called 'wool-packs' or 'ballstones:' some of them near Wenlock have, according to Murchison, a diameter of 80 feet, and they are quarried out, leaving large cavities. The same geologist observes that, though very thick near Wenlock, the limestone thins out so rapidly in its range to the south-west, that even in the interior of the Ludlow promontory it is represented by thin courses made up of small concretions only, and near Aymestry it is merely represented by a few concretions, varying in size from 2 inches to 2 feet, but still full of beautiful and characteristic corals. It thins out entirely in Radnorshire, and is very feebly represented in Brecon, Caermarthen, and Pembroke; for, according to Murchison,

its place is only marked in the cliffs of Marloes Bay, west of Milford Haven, by some fossils and a small quantity of impure limestone in grey and sandy shale.

The Wenlock Limestone is well-developed at Malvern (280 feet), Woolhope, May Hill, and Usk. Among the most noted localities, however, are the Castle Hill and Wren's Nest at Dudley, where the limestone has been largely quarried; also Hurst Hill near Sedgley.

The northern end of Wenlock Edge, Benthall Edge, and Gliddon Hill are mentioned by Murchison as the best localities for fossils.

The fossils comprise Corals, Encrinites, Trilobites, Mollusca, and Annelides, including species of *Halysites*, *Favosites*, *Heliolites*, *Omphyma*, *Cyathophyllum*; *Periechocrinus moniliformis*; *Illænus Barriensis* (Barr trilobite), *Encrinurus*, *Phacops Downingiæ*, *P. caudatus*, *Calymene Blumenbachii* (the 'Dudley Locust'), *Pterygotus*; *Orthoceras annulatum*, *Bellerophon*, *Conularia*, *Orthonota*, *Avicula*, *Strophomena*, *Pentamerus*, *Spirifer*, *Orthis*, *Atrypa*, *Rhynchonella borealis*; and species of *Cornulites* and *Tentaculites*.

The limestone is largely quarried for smelting-purposes and lime-burning at May Hill, Ledbury, Woolhope, and Abberley. The Ledbury Marble is an oolitic limestone.

LOWER LUDLOW BEDS. (Murchison.)

The term is derived from the town of Ludlow in Shropshire, and the formation consists of grey sandy shales, locally called mudstones; some of the upper beds are calcareous.

The Ludlow formation is a natural continuation of the Wenlock beds, and the inferior strata contain calcareous nodules, which differ from those of the Wenlock deposit only in being usually of a blacker colour, and which have often been formed round an Orthoceras, a Trilobite, or other fossil as a

nucleus. (Murchison.) The thickness of the formation is about 700 feet at Malvern.

Amongst the fossils are numerous Starfishes, *Palasterina, Palæaster, Palæocoma, Protaster;* many Crustacea, *Pterygotus, Hemiaspis* (4 species), *Eurypterus punctatus, E. Brodiei, Ceratiocaris Ludensis,* Trilobites, &c.; Graptolites; *Cardiola interrupta, Murchisonia Lloydii, Orthoceras Ludense, Phragmoceras, Lituites, Lingula lata.*

In ascending, the strata (according to Murchison) become somewhat more sandy, constituting thick flagstones called 'pendle' by the workmen. They have attracted much attention at a spot near Leintwardine, and have yielded many remains of Crustacea and Starfishes. These beds, says the same authority, form the support of the Aymestry limestone, from which they are usually separated by soft soapy beds, in parts an imperfect fuller's earth. It is the decomposition of this unctuous fuller's earth (provincially Walker's earth) beneath heavy masses of the limestone which rest upon it, which has occasioned numerous landslips both near Ludlow and in neighbouring parts of Herefordshire. The Lower Ludlow Shale as described by Murchison occupies the escarpments and contiguous valleys of the Ludlow rocks which range from Shropshire by Presteign to Radnor Forest, and also large undulating tracts of the western parts of Shropshire or contiguous parts of Montgomeryshire. In the Usk, Tortworth, Woolhope, and Malvern districts it is well known.

BANNISDALE SLATES.

IRELETH SLATE GROUP in part. (Sedgwick.)

This group, as developed in the Lake District, is placed on the horizon of the Lower Ludlow and Wenlock Shale.

The Bannisdale Slates are described by Mr. Aveline as consisting of sandy mudstones divided by thin bands of hard

sandstone and occasional beds of grit. The sandy mudstones are much jointed and roughly cleaved, never making good slates, but often large rough slabs, quarried for paving or building stones. The total thickness of the formation is about 5,200 feet.

Fossils are scarce: they include *Rhynchonella navicula* and *Phacops Downingiæ*.

The lowest beds are seen near Kirkby Lonsdale.

AYMESTRY LIMESTONE. (Murchison.)

The Aymestry or Ludlow Limestone occurs in beds of a concretionary character, though this feature is not so conspicuous in them as in the Wenlock Limestone. It is of a bluish-grey and mottled colour, containing numerous layers of shells and corals, and associated with it are beds of shale. It occurs in strata from one to five feet in thickness, but these are very impersistent. Salter indeed regarded it as only a calcareous condition of the Lower Ludlow formation. It may be traced in Herefordshire, Shropshire, and Staffordshire, where it is often extensively worked. South-west of Aymestry it thins out, but it is represented at Usk, May Hill, Abberley, Malvern, &c. Its thickness may reach from 30 to 40 feet.

The fossils include *Protaster*, *Palæaster*, *Phacops*, *Calymene*, *Acidaspis*, *Ceratiocaris*, *Pterygotus*, *Slimonia*; also many species of Mollusca, *Pentamerus Knightii*, *Rhynchonella*, *Lingula*, *Strophomena*, *Atrypa*, *Bellerophon*, &c.

UPPER LUDLOW BEDS. (Murchison.)

These beds consist of flaggy arenaceous shale, with beds of thin shelly limestone. Some of the lower beds are termed mudstones. Their thickness near Ledbury is 140 feet.

The beds yield among Crustacea, *Eurypterus*, *Pterygotus*,

Hemiaspis, Slimonia, Phacops, Homalonotus Knightii; also *Orthoceras bullatum*, Pteropods, Gasteropods, Lamellibranchs, and Brachiopods.

The base of the rock is sometimes marked by calcareous shelly courses, containing *Terebratula* (*Rhynchonella*) *navicula*, and *Leptæna lævigata*.

The beds are well shown at Ludlow, Ledbury, Malvern, Abberley, near Usk, &c. They are extensively quarried for building purposes.

The uppermost Ludlow rocks consist of finely laminated greenish-grey sandstones, overlaid by the Ludlow Bone-bed—a thin layer, of from one inch to a foot in thickness, made up of a mass of bony fragments of fish-defences, coprolites, spines of *Onchus tenuistriatus*, and fragments of *Pteraspis*—some of a mahogany hue, others black—also remains of Crustacea (*Ceratiocaris ?*).

KIRKBY MOOR FLAGS.

KENDAL GROUP. (Sedgwick.)

This formation includes red calcareous flagstones and grits, sometimes in thick beds, and of coarse texture; also bands of coarse slate and tilestone.

It is placed on the horizon of the Upper Ludlow series; and it passes downwards into the Bannisdale Slate group. It extends from Benson Knot, south of Kendal, through Kirkby Moor to the Lune.

The upper part contains casts and impressions of *Terebratula, Orthis, Orbicula, Pterinea, Avicula, Orthonota, Turritella, Orthoceras*.

The most common and characteristic species are stated by Mr. Aveline to be *Holopella gregaria, H. conica*, and *Chonetes lata*.

The beds occur at Hay Fell, Kendal, &c.

DOWNTON SANDSTONES.

The word 'Tilestones,' originally a local term in Caermarthenshire and Breconshire, was first used by Murchison to designate the beds between the Upper Ludlow Rocks and Old Red Sandstone.

The Ludlow Bone-bed is capped by light-coloured, thin-bedded, and slightly micaceous sandstones, which have been quarried near Downton Castle, and have been called the Downton Sandstones: this term is now used for the lower portion of the Tilestones, the Ledbury Shales constituting the upper portion.[1]

These rocks consist of red, grey, and yellow flags, and micaceous sandstones, attaining a thickness of 100 feet: in many of their features they are connected with the Old Red Sandstone.

Murchison first observed this apparent passage at Hay, in Brecon. Junctions may be observed in Caermarthenshire, Pembrokeshire, Herefordshire, Gloucestershire, Worcestershire, and Shropshire.

The town of Ledbury stands partly on these junction beds. They are quarried at Dymock.

At Malvern, the Downton sandstones are about 100 feet in thickness: they consist of sandstones and marls of different tints—red, grey, and yellow.

The beds contain *Pterygotus*, *Hemiaspis*, *Beyrichia*, some Phyllopods, Annelids, *Lingula cornea*, and other Mollusca, *Onchus* and *Pteraspis*, also traces of land plants

[1] The word 'Tilestones' (happily abandoned by Sir R. I. Murchison) is altogether inappropriate. There is not a stone capable of being formed into a *tile*, from the Downton Sandstone to the Cornstones of Wall Hills; but there are thin muddy marls over the Downton beds, which would have been tilestones had they sufficiently hardened, and which are doubtless equivalents of the true tilestones. (Rev. W. S. Symonds.)

(probably Lycopodiaceous seeds), the oldest yet known in England and Wales.

Murchison has stated that the tilestones are visible all along the eastern frontier of the Silurian rocks, and scarcely exceed 40 or 50 feet in thickness.

LEDBURY SHALES.

This group, which rests conformably upon the Downton Sandstones, constitutes the passage-beds between the uppermost Silurian rocks and the Old Red Sandstone.

It comprises red, grey, and purple marls, shales, and sandstones, having at Malvern a thickness of 300 feet.

The section exposed near Ledbury was described by the Rev. W. S. Symonds—the beds contain *Pterygotus* and *Eurypterus* among the Crustacea; also *Onchus*:—

Old Red Sandstone.	Red marls with grey and reddish sandstone, *Pteraspis* and *Cephalaspis*.
Ledbury Shales	Grey marl passing into red and grey marl and bluish-grey rock (Auchenaspis-grits), with *Auchenaspis*, *Cephalaspis*, *Onchus*, *Pterygotus*, *Lingula*, &c. 20 feet.
	Purple shales and thin sandstones, 34 feet.
	Grey shales and grit, with *Cephalaspis* and *Pterygotus*, 8 feet.
	Red and mottled marls, and thin sandstones with *Lingula*, *Pteraspis*, 210 feet.
	Downton sandstone, 9 feet.

CHAPTER III.

OLD RED SANDSTONE AND DEVONIAN.

OLD RED SANDSTONE.

THE Old Red Sandstone consists of red and grey micaceous and mottled sandstones, sometimes false-bedded, quartzose conglomerates, slaty micaceous marls, and shales. Its name, however, bespeaks its most prominent character. In some localities bands of nodular or concretionary limestone called 'cornstones' occur; and ripple-marks are met with on the surfaces of some of the beds of sandstone. The maximum thickness of the series may be taken at about 10,000 feet, but in many places it would appear that an estimate of 4,000 or 5,000 feet is sufficient.

It has been observed to pass insensibly in places into the Silurian rocks below, the passage beds called Downton Sandstones and Ledbury shales belonging perhaps as much to one system as to the other.

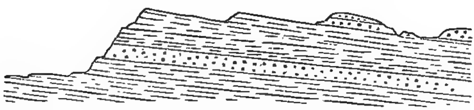
Three divisions are generally made in the Old Red Sandstone, as follows:—

	Upper	Red and variegated sandstones, and quartzose conglomerates. *Holoptychius, Pterichthys.*
Lower or Cornstone Group	Middle	Marly sandstones and flagstones, red shale, and thin cornstones. (Brownstone series.) *Cephalaspis.*
	Lower	Pale coloured sandstones, red and variegated marly beds with cornstones in lower part. (Cornstone series.) *Pterygotus, Pteraspis, Cephalaspis,* &c. About 2,500 feet.

The Old Red Sandstone extends from near Bridgenorth in Shropshire, southwards, through a considerable portion of Herefordshire, Monmouthshire, and Brecknockshire, into Glamorganshire, Caermarthen, and Pembroke.

FIG. 7.—*Section of Old Red Sandstone on the north-west escarpment of the Black Mountains, on the borders of Herefordshire.*[1]

(Sir R. I. Murchison.)



[The beds consist of red sandstone and quartzose conglomerate.]

Near Malvern and Abberley, the Old Red Sandstone rests on the Ledbury Shales and Ludlow Rocks. Quartz conglomerates are conspicuous at Kymin Hill, Monmouth. In the Forest of Dean country, the nodular beds of cornstone give the rock a conglomeratic appearance. The Vans (Fans) of Brecon are formed of the Old Red Sandstone, the upper beds consisting of white quartz-conglomerate.

Slaty cleavage in nearly vertical lines traverses the beds around Milford Haven. Upper Old Red Sandstone, consisting of conglomerate, red and grey sandstone, and cornstone, 600 feet, has been observed in Anglesea, resting unconformably upon the older rocks, and overlapped by the Carboniferous Limestone. Some traces of red conglomerate and sandstone, belonging to the upper division, have been mentioned as occurring in the Lake district: they rest unconformably upon the Silurian rocks, and indeed contain pebbles with Cambrian and Silurian fossils. The beds are overlaid conformably by Carboniferous Limestone, and, according to

[1] This woodcut is borrowed from Mackintosh's *Scenery of England and Wales*, p. 142.

Sedgwick, beds of red sandstone, of similar type to that of the Old Red Sandstone, alternate in thick masses with the limestone. The Old Red Sandstone, or rather conglomerate, is stated by Dr. Nicholson to attain a thickness of from 2,000 to 3,000 feet in the Ulleswater area, and of about 150 feet beneath the Pennine Chain. Professor Harkness considers its thickness in the Vale of Birbeck as 270 feet. The upper beds of the Old Red Sandstone occur in Denbighshire.

The Old Red Sandstone may be traced near Berkeley in Gloucestershire, where it passes downwards into the Silurian rocks. It appears in places near Bristol, and on the summit of the Mendip Hills. (See fig. 8.) Its occurrence in West Somerset, North Devon, and South Devon, is not disputed: at present, the beds of the same mineral type as the Old Red Sandstone are grouped with the Devonian rocks, of which they form the base.

The organic remains of the Old Red Sandstone are few. Some plant-remains (*Sphenopteris*, *Knorria*, &c.) have been observed, but the most conspicuous fossils are those belonging to the classes Crustacea and Pisces. Of Crustacea the genera include *Pterygotus* and *Stylonurus*; of Fish the genera are many, and include *Pterichthys*, *Holoptychius*, *Cephalaspis*, *Pteraspis*, *Coccosteus*, &c.

The physical and palæontological evidence goes to prove that the Old Red Sandstone was essentially a freshwater deposit, formed in large lacustrine areas.

Old Red Sandstone yields a strong loamy soil, which is generally fertile: many orchards are situated upon it, and a few hop-yards. In some places, however, the soil is wet and boggy, and consequently unproductive. The Cornstones form the richest land in Herefordshire.

Some beds known as 'firestones' have been employed for making hearths. Many sandstone beds are used for building-

purposes, and these, as well as the cornstones, are often used for mending roads. The conglomerates are sometimes used as cyder-millstones.

Old Red Sandstone, of a greyish-brown colour, quarried near Chepstow, was used in the construction of Tintern Abbey. The sandstone is quarried near Monmouth, Ledbury, &c.

The Three Elms Stone, near Hereford, is also much quarried for building-purposes.

DEVONIAN.

The term Devonian was proposed by Sedgwick and Murchison, because from a study of the fossils Mr. Lonsdale considered that the strata constituted a natural history group intermediate between the Silurian rocks and the Carboniferous Limestone.

The Devonian rocks of West Somerset, Devon, and Cornwall consist of a series of slaty rocks, grits, sandstones, and limestones. Much has been written upon the exact relations of the different divisions that have been made out, and considerable difference of opinion has been expressed. By many authors they are considered as the marine equivalents of the Old Red Sandstone, but this classification is by others admitted to be doubtful, and Prof. Jukes expressed his opinion that the greater part of the Devonian strata were of Lower Carboniferous age. Under such circumstances we cannot do better than consider the beds separately as Devonian, while at the same time pointing out some of the ascertained facts and some of the conclusions which they foreshadow. The beds are best displayed in the coast sections between Barnstaple Bay and Lynton, and the following series of beds has been made out in North Devon:—

Upper Devonian	Pilton Beds	Pilton and Barnstaple Beds.
		Braunton Beds.
		Croydon Beds.
	Baggy and Marwood Slates.[1]	
	Pickwell Down Sandstones.	
Middle Devonian	Morte Slates or Mortehoe Beds.	
	Ilfracombe and Combe Martin Beds.	
	Hangman Grits or Martinhoe Beds.	
Lower Devonian	Lynton Slates.	
	Lynton Sandstone or Foreland Group.	

LOWER DEVONIAN.

LYNTON SANDSTONE (FORELAND GROUP).

This series consists of hard red and grey sandstones with some slaty beds, and is developed at the northern end of the Quantock Hills, at Dunster, Porlock, and the North Foreland.

The beds are unfossiliferous, and are admitted to be identical in character with beds of Old Red Sandstone.

LYNTON SLATES.

This division comprises a series of gritty slates, shales, and sandstones, about 1,500 feet in thickness, containing, according to Mr. Etheridge, *Spirifera*, *Orthis*, *Fenestella*, *Favosites*, *Bellerophon globatus*, *Orthoceratites*, Crinoids, etc.

MIDDLE DEVONIAN.

HANGMAN GRITS (MARTINHOE BEDS).

This group consists of red and grey grits, shales, and sandstones, well seen at Woodabay, and they resemble, according

[1] The Marwood Beds were taken as the uppermost Devonian by Sedgwick and Murchison.

to Mr. Etheridge, the lower sandstones of the Foreland and the higher beds of Pickwell Down. They attain a thickness of about 1,500 feet, and extend from Croydon Hill to Trentishoe (=Trentishoe Beds). They contain few fossils.

ILFRACOMBE GROUP.

Combe Martin Limestone.

Above the Hangman Grits is a series of calcareous silvery shales or slates with bands of limestone, containing *Stringocephalus Burtini* (= 'Stringocephalus limestone'), and *Streptorhynchus*, *Cyathophyllum*, &c., extending in a band from near Withycombe to Ilfracombe and Lee Bay, and attaining a thickness of about 4,000 feet. The limestone beds of the Quantocks belong to this series.

The bands of limestone form a small proportion of the series, but they are in many places worked for lime. In some places, as at Kentisbury, contemporaneous Igneous rocks have been noticed by Mr. Etheridge; the beds are worked for road-metal.

MORTE SLATES (MORTEHOE GROUP).

This series comprises the pale grey and purple unfossiliferous glossy slates of Challacombe and Mortehoe, having a thickness estimated at from 3,000 to 4,000 feet.

They extend from the Oakhampton Slate Quarry, near Wiveliscombe, to Mortehoe: they contain no recognised limestone bands. The valuable spathose iron-ore of the Brendon Hills occurs in these beds.

The slaty beds of Hestercombe may perhaps be on this horizon, as also those of Lundy Island.

UPPER DEVONIAN.

PICKWELL DOWN SANDSTONES.

Woolacombe Sandstone.

These consist of red micaceous sandstones, shales, and conglomerates. They extend from Pickwell Down to near Wiveliscombe, and partake much of the character of Old Red Sandstone. They are about 3,000 feet in thickness, and contain hæmatite.

BAGGY AND MARWOOD SLATES (CUCULLÆA ZONE).

These consist of a series of slates and sandstones characterized by *Cucullæa* (*C. trapezium*), and extending from Baggy Point to Marwood, and according to Mr. Etheridge as far as Dulverton.

In the sandstones of Sloly Quarry, *Lepidodendron* and *Calamites* are found. Mr. Salter identified the Marwood Beds with the Upper Old Red Sandstone.

PILTON BEDS.

Trilobite Slates.

The Pilton Group consists of a series of calcareous sandstones, grey shales and slates, and nodular bands of limestone, containing *Strophalosia caperata*, *Spirifer Barumensis*, *Phacops latifrons*, *Bellerophon*, *Aviculo-pecten*, *Encrinites*.

Top Orchard Quarry is a well-known locality for the fossils. This group includes the Beds of Croydon, Braunton, Pilton, and Barnstaple: south of the last-mentioned town, the beds pass gradually into the Culm-measure Series. (See p. 106.)

RELATIONS OF OLD RED SANDSTONE AND DEVONIAN.

In attempting to parallel the Devonian strata with equivalent beds in other parts of the country, the first inquiry is naturally concerning the relations between them and the overlying true Carboniferous rocks. This relation is not quite clear in South Devon, owing to disturbances; but, in North Devon, the beds pass gradually one into the other. Now these Carboniferous rocks are generally classed with the Millstone Grit and Coal Measures, but there are several calcareous bands at the junction of the Culm-measures and Devonian strata, which have been regarded as partly representing the Mountain Limestone.

In South Wales, about Haverfordwest, the Carboniferous Limestone has become much attenuated; while in Ireland the Limestone becomes in certain localities replaced by the Carboniferous slate which generally underlies it. When we trace the Carboniferous limestone northwards beyond Derbyshire, the calcareous element becomes less, and the series consists of bands of limestone intercalated with shales and sandstones, and containing seams of coal.

Looking at these changes, it seems only reasonable to consider that at least some of the upper portions of the Devonian series may be paralleled with the Lower Carboniferous strata of other districts.

It is admitted on all sides that the lowermost Devonian strata are identical in character with beds of Old Red Sandstone: it would seem, therefore, that the boundary-line between the Old Red Sandstone and Carboniferous systems must be drawn somewhere between the Upper and Lower Devonian strata. Such a line, however, may never be fixed with precision. The Devonian area exhibits, on the whole, a more uniform series of conditions than we find in other

districts to have characterized the same period. If we regard the Old Red Sandstone as entirely formed in fresh waters, we require a considerable barrier to separate the purely marine area of the Devonian slates and limestones from the lacustrine sands of the Old Red period; and such a barrier (if it ever existed) must be drawn somewhere between the Mendip and Quantock Hills, and there is no physical evidence to support it.

Any one who examines the limestones of Torquay, Newton, and those of the Mendip Hills and South Wales, cannot fail to be struck with the general identity of their lithological characters: at the same time it is clear that the fossil contents are on the whole different.

Nowhere do we find the Devonian strata immediately overlying the uppermost Silurian rocks, and nowhere is there exhibited any horizontal passage of the Old Red Sandstone into slates of the Devonian type. There is no base to the Devonian series, and Sedgwick admitted it to be the safest plan to place the Cornstone group below all the groups of Devonshire.[1]

Mr. Jukes regarded the red sandstones of the northern portion of the Quantock Hills, those of Dunster, Minehead, and Porlock, as of Old Red Sandstone age. The overlying slates of Lynton, Ilfracombe, &c., he identified with the Carboniferous slate; while the sandstones of Pickwell Down, Haddon Down, and Main Down, he regarded as probably a repetition of Old Red Sandstone brought up by a concealed fault; and he considered that the overlying slates of Marwood, Braunton, and Pilton again represented the Carboniferous slate which passed gradually upwards into the Culm-measures.

Mr. Jukes thus paralleled the groups on either side of the fault:—

[1] *Brit. Pal. Rocks,* p. xxiv.

South of Fault	North of Fault
Pilton and Barnstaple beds . . .	Morte slates.
Braunton beds	Ilfracombe beds.
Croyde beds	Hangman grits.
Baggy and Marwood slates . . .	Lynton slates.
Pickwell Down sandstones . . .	Lynton sandstone.

The slaty rocks and associated limestones of South Devon and Cornwall are so much broken up and disturbed, compared to the equivalent beds in North Devon, that no very accurate parallels have been made.

Large masses of granite and many other rocks of igneous origin, intersect or protrude through the 'killas' or clay-slate of Cornwall and Devon.

The Limestones of Plymouth (Plymouth rag), Chudleigh, Ashburton, Ipplepen, Berry Pomeroy, Torquay, St. Mary Church, and Newton Abbot (the Great Devon Limestones) are as well known from their purely economic value for marble, building- and paving-stone, as some bands of the rock are from the richness of their palæontological contents. The numerous remains of corals render the rock, when polished, very beautiful: it is called Madrepore marble. These corals belong to the species *Heliolites porosa*, *Favosites polymorpha*, *Cyathophyllum cæspitosum*, *Astræa pentagona*, &c.[1] Among the Mollusca, *Orthoceras*, *Clymenia*, *Goniatites*, *Loxonema*, *Murchisonia*, *Rhynchonella*, *Spirifera*, *Stringocephalus Burtini*, &c. are found.

Trilobites likewise are met with, as *Phacops latifrons*, *Bronteus flabellifer*, &c.

Mr. Etheridge places these limestones on the horizon of the calcareous beds of Ilfracombe. They appear to form the highest beds of the South Devon strata, being connected,

[1] It is considered that the masses of annulated chalcedony, called Beekite, found in the neighbourhood of Torquay, are Devonian corals more or less completely replaced by silica, for they are sometimes hollow, and in other instances contain a nucleus of fossil coral.

perhaps, by a thin series of shales with the Culm-measures above. Evidence recently obtained by my colleague Mr. C. Reid at Chudleigh, seems to indicate the conformability there of the Culm-measures and Devonian Limestone. The main mass of the South Devon slates which underlies the Limestone, itself rests on Red Sandstones, similar in character to Old Red Sandstone. These beds are well shown at Cockington, near Torquay.

Dr. Holl considers that in South Devon there is a complete unconformability between the base of the Culm-measures and the underlying Devonian rocks. The beds of pale greenish and grey argillaceous slates, sometimes soft and silvery, and often veined with quartz, that extend from Callington, north of Plymouth, to Ashburton, he regards as the lower group of Devonian rocks; while the group of grey slaty rocks of Mount Edgcumbe, Kingsbridge, Dartmouth, and Totnes, constitute, in his opinion, an upper group.

It is only right to state that Mr. Jukes questions the unconformability of the Culm-measures and Devonian rocks in this southern area; the discordant positions can, he thinks, be accounted for by concealed dislocations and unrecognized contortions; and any one who has personally surveyed the country will agree with him that the faults and other disturbances are very numerous. Nor can the palæontological evidence be used for determining stratigraphical relations: these must be first made out by long-continued, careful, and minute survey. Such a survey will, no doubt, prove the stratigraphical relations of the beds. Then the fossils may be placed in their true horizons. In the mean time every fact observed will help the solution of the problem, whether it be the record of some new section, or the determination of a suite of fossils from some definite stratum. Fossils collected are useless for purposes of classification unless

the *exact* locality be known: localities given simply as Newton, Chudleigh, or Torquay are valueless.

The following classification of the beds has been made by Mr. Etheridge:—

	S. Devon.	Cornwall
UPPER DEVONIAN. (*Clymenian.*)	Newton ?	Petherwin limestones and slates (Clymenia limestone), Tintagel and De la Bole slates.
MIDDLE DEVONIAN. (*Eifelian.*)	Dartmouth slates, Dartington, Ogwell, Torquay, Newton, and Plymouth limestones, Lummaton and Ramsleigh, &c.	Padstow, Looe grits (=Hangman grits), Polperro.
LOWER DEVONIAN. (*Hercynian.*)	Meadfoot slates, Yealmpton-Creek and Black-Hill slates, Looe Island.	St. Veep, Polruan, Polperro, and Fowey grits and slates.

The age of the Petherwin limestone has been matter of much dispute: by some authorities it is regarded as Middle Devonian.

In Cornwall particularly but little is known of the stratigraphical relations of the slaty rocks. Mr. Pengelly has obtained from the lower beds *Phyllolepis concentricus*, and at Looe remains of *Pteraspis*.[1] He also obtained a scale of *Phyllolepis* at the base of the cliff between Meadfoot Beach and the Thatcher Rock, Torbay.

Economic Products, &c., of Devonian Rocks.

The Killas, shillet, or clay-slate of Cornwall and Devon varies very much both in colour and in character in different

[1] Mr. C. W. Peach (in 1844) discovered Fish-remains in these rocks.

places. It is the matrix of much of the mineral wealth of the district, including ores of tin, copper, silver, lead, and iron.

Of Cornish slates, those of De la Bole near Camelford, and Tintagel, are most highly valued. The De la Bole Quarries produce besides roofing-slates, flagstones used for paving-purposes, tombstones, &c.

Devonian slate called Kingstone Stone has been quarried near Taunton, on the Quantock Hills. At Hestercombe the slate by contact with a syenitic dyke, has become metamorphosed and forms in places a hone-stone.

Grey micaceous slates, apparently very much altered, are met with at Salcombe and Bolt Head. Slate has been quarried at Tavistock, Kingsbridge, &c. At Tavistock, Devonshire oilstones were formerly obtained.

Rock Crystal (Cornish diamond) occurs in many parts of Cornwall, at Tintagel, De la Bole Slate Quarries, Carnbrea, &c.

CHAPTER IV.

CARBONIFEROUS.

THE term Carboniferous is applied to a great system of formations, which are intimately linked together, and which in our country are the great coal-producing rocks. It is, however, only in the upper portion or in the Coal-Measures proper that coal is usually worked.

Although connected with the Old Red Sandstone by gradations that forbid any sharp line of demarcation being drawn, yet the organic remains of the Carboniferous rocks are distinct from those of the Old Red Sandstone, and they were evidently deposited under very different physical conditions. As they comprise a mass of strata of great thickness, it is well to mark the distinction by classing them as a different system under the comprehensive term of Carboniferous.

The Carboniferous rocks were mostly formed in the sea and not far from the land, for the remains of terrestrial vegetation occur in them at all horizons, and hence the period has sometimes been termed the Phytozoic Period, or Age of Plants.

Very marked lithological changes occur in the beds when traced across England. The Lower Limestone Shales of the south are scarcely represented as a distinct group in the north; the Mountain Limestone of the south and centre loses its marked calcareous character in the far north, and becomes a series of limestones and sandstones with coal; the Millstone Grit exhibits many modifications in different localities; the Yoredale Rocks scarcely noticed in the south attain great

importance in the north; while the Coal-Measures, perhaps the most persistent in type of the series, is at least a very unprofitable member in Devonshire.

The following are the principal local divisions that have been made in the Carboniferous rocks:—

1. *Northumberland and Durham.*

Coal-Measures (1,500 to 2,000 feet).	Upper coal-measures with thin coals. Middle coal-measures with thick coals. Lower coal-measures or Gannister beds with thin coals.
Millstone Grit (400 feet).	Alternations of grit and shale.
Yoredale rocks and Carboniferous Limestone series.[1]	Alternations of limestone, coal, shale, grit, and sandstone.
Tuedian beds.	White and grey sandstone with greenish grey shales, cement-stones, and limestones.

The Yoredale Rocks are from 500 to 540 feet in thickness; and the lower Carboniferous beds from 1,100 to 2,000 feet.

2. *Lancashire, Yorkshire, and Derbyshire.*

Coal-Measures (2,000 to 7,000 feet).	Upper coal-measures with limestones and thin coals. (Lancashire only.) Sandstones. Middle coal-measures with thick coals. Lower coal-measures or Gannister[2] beds with thin coals.
Millstone Grit (300 to 3,000 feet).	Rough Rock. Shales, often absent. Haslingden Flags. Shales. Middle Grits. Shales. Kinder Scout Grit.

[1] Mr. G. A. Lebour has suggested the term 'Bernician Series' for this group, because no Yoredale rocks proper, and no Scar Limestones proper, can be shown to exist in it.

[2] The term 'Gannister' or 'Calliard' is used to designate a peculiarly hard siliceous bed, forming the floor of some of the coals of this series. (Hull.) It is often full of the rootlets named *Stigmaria ficoides.*

Yoredale Rocks (300 to 2,000 feet).	Shales. Yoredale Grit. Shale, with hard thinly-bedded sandstones in places (Yoredale sandstones). Black shales with thin earthy limestones.
Carboniferous Limestone (400 to 1,200 feet).	

3. *South-West of England and South Wales.*

Coal-Measures (5,000 to 12,000 feet).	Upper coal-measures. Pennant grit. Lower coal-measures.
Millstone Grit or 'Farewell rock'	(300 to 1,000 feet.)
Upper Limestone Shale Carboniferous Limestone	(1,000 to 3,000 feet.)
Lower Limestone Shale.	(300 to 500 feet.)

LOWER CARBONIFEROUS.

TUEDIAN GROUP.[1]

The lowest beds of the Carboniferous series in Northumberland and the Tweed valley have been classed as the Tuedian Group by Mr. G. Tate. They consist of shales, slaty and calcareous sandstones, thin beds of argillaceous limestone, sometimes magnesian, and chert, with remains of plants, but no workable coal. The thickness is about 1,000 feet. The beds contain remains of plants, mollusca, and fish.

In the eastern part of the Eden Basin, resting on the Upper Old Red Sandstone, is a series of shales, impure limestones, calcareous conglomerates, obliquely laminated red sandstones sometimes containing pebbles of quartz and assuming a conglomeratic character, and which pass upwards into the principal mass of the Carboniferous Limestone. This series, lately described by Mr. Goodchild, includes the con-

[1] The Tuedian Group and the Lower Limestone Shale are homotaxeous with the Calciferous Sandstone group of Scotland.

glomerates of Cross Fell (formerly regarded as Old Red Sandstone), the beds of Ash Fell, Roman Fell, &c., and is probably on the horizon of the Calciferous Sandstone series of Scotland. The thickness of the series is from 800 to 1,000 feet, and its character is changeable.

In the Isle of Man there are certain beds which have been assigned to Old Red Sandstone: they occur north of Peel, and fringe the Carboniferous Limestone north of Castletown. They consist of brecciated conglomerates, and of fine breccia interstratified with red sandstones; they occasionally contain beds of cornstone, and rest unconformably upon the Skiddaw Slates. The beds, however, pass conformably up into the Carboniferous Limestone, and this, in the opinion of Mr. J. Horne, is presumptive proof that they are really of Lower Carboniferous age. He considers that the beds may be correlated with the Calciferous sandstone series of Scotland.

LOWER LIMESTONE SHALE.

This term is applied in South Wales, Gloucestershire, and Somersetshire, to the beds between the Carboniferous Limestone and Old Red Sandstone.

They consist of clays and shales, sometimes mottled, sandy and micaceous, of various tints, blue, greenish-grey, and brown; with occasional beds of tough bluish limestone, like Carboniferous Limestone, in the upper part, and alternating with beds of sandstone in the lower. In fact they form a passage between the Old Red Sandstone and the Carboniferous Limestone. Sometimes the shale is very feebly represented, occurring in thin beds rapidly alternating with limestone.

In the gorge of the Avon the aggregate thickness of the beds is stated to be 500 feet; in the Forest of Dean 165 feet; at Caldy Island 400; and on the Mendip Hills 500 feet.

Amongst the fossils are *Leptæna*, *Strophomena*, *Orthis*, *Chonetes*, Crinoidal remains, &c.

At the base of the Lower Limestone Shales of Bristol and the Mendip Hills is found the fish-bed or palate-bed, a conglomeratic bone-bed, so named on account of the number of palatal teeth and spines of fish met with in it. The remains are those of *Psammodus*, *Cochliodus*, &c.

Trilobites are met with near the junction with the Old Red Sandstone on the Mendip Hills.

At Farlow in Shropshire, according to Prof. Morris and Mr. G. E. Roberts, the passage beds between the Old Red Sandstone and Carboniferous Limestone, consisting of yellow sandstones and pebble-beds, yield the palatal teeth of fish, and one bed, called the 'Pterichthys bed,' yields *P. macrocephalus*.

In the South-West of England and in South Wales, the Lower Limestone Shales form a band of generally depressed land surrounding the Old Red Sandstone, bounded again by an escarpment of the Carboniferous Limestone. Swallow holes frequently mark its junction with the newer rock.

From its appearance, it has sometimes led to fruitless searches for coal.

CARBONIFEROUS OR MOUNTAIN LIMESTONE.

GREAT SCAR—(SCAUR) LIMESTONE. (Sedgwick.)

The Carboniferous Limestone is generally a tough bluish-grey crystalline limestone, which emits a sulphurous smell when fractured. It occurs in massive beds, some of which are oolitic in structure. It is frequently traversed by veins of calc-spar, and by strings or nodules and bands of chert. Layers of chert are sometimes met with which merge gradually into the masses of limestone.

The rock is locally much stained by iron-ore.

The beds are fossiliferous, and chiefly of organic origin; but sometimes few traces of organic remains are discernible.

The most abundant are the Corals *Lithostrotion* (*striatum*, *basaltiforme*, *Lithodendron*, *Syringopora reticulata*, *Lonsdaleia floriformis*, *Zaphrentis*, and *Cyathophyllum*; Bryozoa, such as *Fenestella* and *Polypora*; Crinoids, including *Cyathocrinus*, *Actinocrinus*, *Platycrinus*, &c.; Molluscs, *Productus semireticulatus*, *P. giganteus*, *Spirifera*, *Orthis resupinata*, *Euomphalus*, *Bellerophon*, *Orthoceras*, *Goniatites*, *Pleurotomaria*, &c.; and Trilobites, *Phillipsia*, *Griffithides*, &c.

Edward Forbes observed (in 1854) that many circumstances warrant the supposition that the Carboniferous Limestone of most regions was a deposit in shallow water; and a fact in support of this was stated to be the occurrence of traces of colouring on certain shells, or of the pattern-markings derived from the original colouring.[1]

In the North of England the limestones are generally spoken of as 'Scar Limestones.' 'In passing through Northumberland (to quote Professor Phillips) they become continually more and more subdivided by interpolations of sandstone, shale, and coal, till on the sea-coast, north of Belford, a part of this series contains no less than 13 bands of limestone (121 feet in total thickness), separated by many times their thickness of sandstone and shale, and under the whole lie workable seams of coal. The character of the surface of all the western and north-western part of Northumberland corresponds to this change of the component strata. Instead of the beautiful green pastures which delight our eyes amidst the calcareous dales of Derbyshire and Yorkshire, wide, heathy, and boggy moorlands overspread the surface of sandstones and shales; and we seem to wander in a region of barren Coal-Measures, rather than on the range of the thickest Carboniferous Limestones.'

[1] The results of recent dredgings show that coloration on shells occurs in deep water.

Under Ingleborough there is a nearly undivided calcareous mass, 400 or 500 feet thick; but at Alston Moor there are no less than twenty different limestones, amounting altogether to 470 feet in thickness, obscured by the interposition of no less than 1,686 feet of sedimentary strata. Farther north these mechanical admixtures increase in amount, while the calcareous strata diminish; and at length, in the northern parts of Northumberland, the limestone district has become a valuable coal-field. (Phillips.)

Professor Phillips has given the following estimates of the thickness of the Scar Limestones:—

	Feet
Penyghent	400
Wensleydale	250
Swaledale	120
Alston Moor	1196

The Limestone series (1,000 to 3,000 feet in thickness) forms a narrow band on the eastern side of the Vale of Eden; and bordering the west side of the vale, it forms a belt around the old slaty region of the Lake District between Orton and Egremont.[1]

In the southern part of the Lake District may be mentioned the Kendal grey marble; while, near Egremont, the Cleator Limestone is of local repute.

Near the top of the Carboniferous Limestone at Pendle Hill is the Pendleside Limestone (so called by Mr. Tiddeman), which shows a thickness, with interbedded shales, of about 350 feet. Amongst other rocks are the Great Whernside Limestone (1,000 feet), the Melmerby Scar Limestone, the Dufton Scar Limestone, &c.

In the Isle of Man, the Carboniferous Limestone consists of the Poolvash black marble and limestone group (*Posidonia* schist of Cumming), and of the (lower) Castletown limestone.

[1] At Hesket New Market there are grits, limestones, and shales with thin bands of coal.

The Carboniferous Limestone presents its characteristic features and maintains great uniformity in Leicestershire, Derbyshire, North and South Wales, Shropshire, Monmouthshire, Gloucestershire, and Somersetshire. Its thickness, however, varies much. It is a great calcareous mass, with no marked clay beds or other divisions.

Much of the Carboniferous Limestone of Leicestershire is dolomitic; it is quarried at Grace Dieu, Breedon Hill (Breedon Stone), Ticknall, and other places.

In Derbyshire, the Carboniferous (or Derbyshire) Limestone is well known in the numerous dales whose picturesque scenery is so attractive, while the associated masses of toadstone impart additional interest to it. It attains a thickness estimated by Professor Green at about 1,600 feet.

In Denbighshire and Flintshire, the limestone attains a thickness of from 1,000 to 1,500 feet.

In the Isle of Anglesea occurs the grey and black Pentraeth Limestone, with occasional beds of sandstone. The thickness of the limestone series here is, by different writers, estimated at from 200 to 500 feet.

In South Wales, the Carboniferous Limestone contributes much to the scenery between Bridgend and Cardiff. The Castell Coch Rock and the Trefil Limestone (Brecon) belong to this formation.

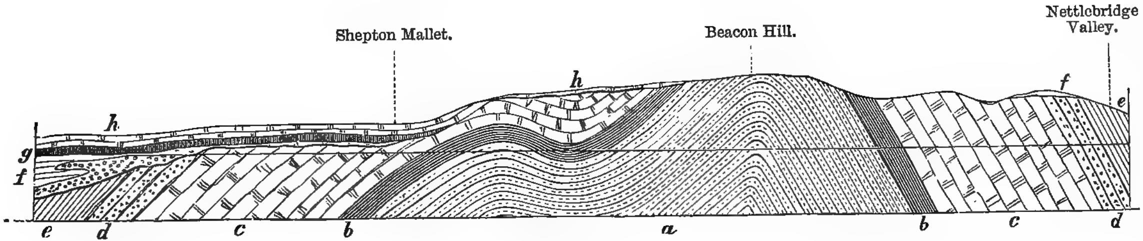
At Caldy Island, the limestone is about 2,000 feet in thickness; in the Forest of Dean, 480 feet; and in the northern part of Glamorganshire, 500 to 600 feet.

In Monmouthshire it is 1,000 feet, and in the Mendip Hills about 3,000 feet in thickness.

A very detailed section of the Carboniferous Limestone, and indeed of the whole of the beds between the Millstone Grit and Old Red Sandstone, was made many years ago by Mr. David Williams, then of the Geological Survey. The higher portion belongs to the Upper Limestone Shale: this includes

FIG. 8.—*Section across the Mendip Hills.*

Horizontal Scale = one inch to one mile.



h. Lower Lias.
g. Rhætic or Penarth Beds.
f. Red Marl and Dolomitic Conglomerate.
e. Coal-Measures.
d. Millstone Grit.
c. Carboniferous Limestone.
b. Lower Limestone Shale.
a. Old Red Sandstone.

alternations of limestone, reddish, grey, or dark, with shales of the same tints, and sandstones red or grey: it contains corals, crinoids, brachiopods, at intervals throughout the mass, which is about 400 feet in thickness. Below comes the Carboniferous Limestone proper, termed by Professor Phillips the 'Scar limestones;' grey, reddish, mottled, brown or black, in colour; partially divided by shales; compact or oolitic, shelly, and crinoidal. This division is about 1,500 feet in thickness.

At Cannington Park, near Bridgewater, there is a mass of limestone, much disturbed, which has by different geologists been classed as Devonian or Carboniferous: it resembles both in lithological character, and is no doubt of Carboniferous age.

At the base of the Culm Measures in Devonshire are impersistent beds of black limestone, which may possibly represent the upper portions of the Carboniferous Limestone.

The Carboniferous Limestone is much quarried for lime. It is largely used for rough buildings and for road-mending, for which purposes it is conveyed to great distances, but from its hardness it is not serviceable as a freestone. Some of the beds are polished and used as marble for ornamental purposes. The Derbyshire marble is found very serviceable for chimney-pieces and other ornaments, and from its varied characters is known as Shelly or Mussel, Bird's eye, Dog's tooth, Entrochal, or Encrinital Limestone.

Some of the beds contain vast assemblages of Crinoids, and are occasionally quarried as marbles; and it is remarkable that in some places, where these beds basset out on the surface, masses are ploughed up from beneath the soil, exhibiting the casts of the inside of Crinoids in chert; these are commonly called *screw-stones*. Blocks of these were heretofore used in the forming of millstones, which were employed instead of the French buhr-stone. In some places

the upper beds partake so greatly of the nature of chert as to be unfit for the purposes of the lime-burner. (Conybeare.)

The soil is very often thin, but when present it is usually a ferruginous loam. It forms good ground for sheep-farms.

The rock, however, frequently juts out to the surface, and gives a rugged and picturesque aspect to the scenery. Many of the cliffs and combes of Somersetshire and the dales of Derbyshire are formed in this rock.

The Carboniferous Limestone yields many springs of water, which find their way through joints and fissures.

Barytes (Sulphate of Baryta) or Heavy Spar occurs in Derbyshire, and has been raised there for use as a pigment, and for the adulteration of white lead. Fluor spar (Fluoride of Calcium) is found in Cumberland and Derbyshire: in the latter county a blue nodular variety is generally known as 'Blue John.'

Elaterite, or mineral caoutchouc, an elastic variety of bitumen, emitting an unpleasant odour, is met with at Castleton.

The Carboniferous Limestone has yielded ores of zinc and lead in the Mendip Hills and Derbyshire, and of lead in Flintshire, Denbighshire, &c.

The Hæmatite of Ulverstone, and the Ironstone shale of Redesdale, belong to the Carboniferous Limestone series; while in some places Iron-ores occur in pockets of the Limestone beneath superincumbent Permian or Triassic rocks.

YOREDALE ROCKS and UPPER LIMESTONE SHALE.

The Yoredale Rocks, named by Professor Phillips from their development in Yoredale (or Wensleydale) in Yorkshire, consist of alternations of flagstones, gritstones, shales, seams of coal, and limestones.

The general sub-divisions, as given by Prof. Phillips, are as follows:—

1. Upper Limestone belt, consisting of alternations of limestones, sometimes cherty, with sandstones, shales and coal-seams. Thickness from 80 to 250 feet.
2. Flagstone series, consisting of alternations of flagstones, grits, shales, coal-seams, and three or four beds of limestone. Thickness from 250 to 400 feet.

Dr. Nicholson has observed that the two most constant members of the series are the 'Tyne-bottom Limestone,' and the 'Main,' 'Great' or 'Twelve-fathom Limestone,'—respectively the lowest and the highest limestones of the group. The former attains a thickness of 22 feet.[1]

The Yoredale Rocks extend from the coast of Northumberland round the western borders of Durham to Ingleborough, and thence through South Yorkshire into Derbyshire.

The following list shows the alternation of beds developed at Teesdale and Alston Moor:—

Limestone.
Sandstone, shale, coal.
Limestone.
Sandstone, shale.
Limestone.
Sandstone, shale, and coal.
Limestone.

The varying thicknesses are thus given by Prof. Phillips:—

	Alston Moor	Swaledale	Wensleydale	Penyghent
Upper Limestone belt	247	250	200	80
Flagstone series	304	250	400	300

Near Halifax the Yoredale strata (including the shales of Hebden Bridge) attain a thickness of 600 feet.

[1] The 'Fell Top Limestone' is a local bed in this series.

In the Ribble Valley and at Bowland Forest, the Yoredale Rocks admit of three great divisions (Geol. Survey) as follows:—

1. Upper Yoredale Grit, consisting of grits and beds of sandy shale, also conglomerate, 1,000 to 1,200 feet.
2. Bowland Shales, black and grey bituminous shales, with beds of sandstone and limestone, 600 to 700 feet.
3. Lower Yoredale Grit, consisting of grits, sandstones, shales, and ironstones, having a thickness of about 600 feet.

In Derbyshire, Mam Tor, or the 'Shivering Mountain,' is composed of rocks belonging to the Yoredale series, which is there sometimes called the Limestone shale. It forms a wet soil, causing landslips of great extent, beneath the Millstone Grit summits.

At Harrogate beds formerly classed with the Millstone Grit have been more recently placed in the Yoredale series by Prof. Phillips: these include the Spofforth Haggs roadstone (10 feet), the Follifoot coal-grit (30 feet), the Almes Cliff grit (50 feet), the Harrogate Tunnel sandstones (20 feet), and the Harrogate roadstone (50 feet): interstratified with these beds are shales, some containing *Stigmaria.*

At Clifton between the Carboniferous Limestone and Millstone Grit, there is an alternation of limestones, shales, and sandstones, 300 or 400 feet in thickness, sometimes classed as the Upper Limestone Shale.

In Leicestershire and Monmouthshire the upper beds of the Carboniferous Limestone consist of limestones alternating with dark shales.

Among the fossils of the Yoredale series, occurring chiefly in the limestones, are *Orthoceras*, *Goniatites sphe-*

ricus, *Posidonomya*, *Productus*. Fossil plants, such as Stigmaria, &c., are likewise met with.

The Yoredale rocks present no very special palæontological features; they comprise beds of marine and estuarine origin, and some that exhibit fluviatile and terrestrial conditions.

Bitumen occurs at Clithero. The lead-mines of Alston Moor, Weardale, Arkendale, are situated in these rocks.

The fine-grained micaceous grit-stones of the lower series are much used for building- and paving purposes, as at Bakewell Edge, &c. The thin coals, as Prof. Phillips observes, are not worth the expense of the fruitless trials in search of them.

Rotten-stone, supposed to be due to the removal of the calcareous portion from cherty limestone, is met with near Ashford and Bakewell in Derbyshire.

The Bishopley Limestone, quarried near Frosterley, Durham, and the Gilling stone, quarried near Gilling, Yorkshire, are limestones of economic value in the Yoredale series.

UPPER CARBONIFEROUS.

MILLSTONE GRIT.

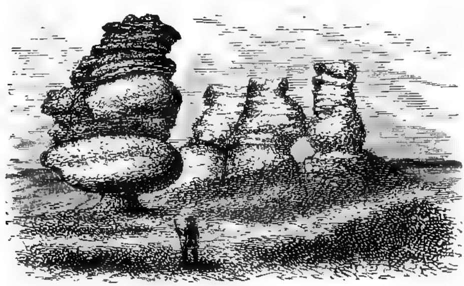
This formation consists of coarse sandstones, grits, shales, and conglomerate, with occasional seams of coal. It generally crops out along the margin of our coal-fields, and indeed forms the immediate foundation upon which they rest; and from the circumstance of its being below the Coal-measures, and containing in the south-west of England and South Wales no valuable coal-seams, it has in those districts been termed the 'Farewell Rock.'

The fossils of the Millstone Grit are few; mollusca are confined to a few limited horizons, but plant remains are not uncommon.

At Alston Moor the Millstone Grit consists of alternations of sandstones, shales with ironstone and coal, attaining a thickness of at least 409 feet. In Swaledale the series embraces coarse gritstones, shales, sandstones, coal, and local interpolations of limestone and chert, having a thickness of 800 feet. At Wensleydale the series is very similar in character, and is about 700 feet in thickness. At Ingleborough and Penyghent the series is but 260 feet in thickness. (Phillips.)

The Brimham Rocks, Pateley Bridge, near Harrogate, are formed of Millstone Grit. They well illustrate the action of atmospheric disintegration on rocks of unequal hardness.

FIG. 9.—*The Idol Rock, Brimham. Pulpit Rocks to the right.*[1]



The Plumpton rocks (Knaresborough grits), once believed by some geologists to be Permian, have recently been determined by Mr. J. C. Ward to be Millstone Grit.

Near Bradford the Ilkley Crags are formed of Millstone Grit; at Horsforth, flags are worked, and the upper beds (80 to 180 feet in thickness) yield the famous 'Yorkshire stone'

[1] This woodcut is borrowed from Mackintosh's *Scenery of England and Wales*, p. 122.

used for building and other purposes. At Gatherly Moor, near Richmond, the Millstone Grit is quarried.

In the Escarpment of the Rough Rock near Bury, north of Rochdale, is the Feather Edge Coal, which has been extensively mined.

The following divisions of the Millstone Grit in Yorkshire and Derbyshire have been determined by the Geological Survey :—

	Feet
Rough Rock (First Grit)	50 to 60
Shales (impersistent)	
Flags [Haslingden Flags (Second Grit)] . .	60 to 100
Shales	75 to 150
Middle Grits and Shales (Third Grit) . . .	100 to 175
Shales and sandstones [Sabden Valley shales (1,500 to 2,000 feet)]	300 to 500
Kinder Scout Grit (Fourth Grit)	500 to 700

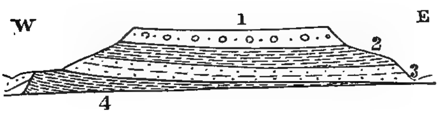
The several divisions are not always represented, and they are subject to great changes in thickness.

The name Kinder Scout Grit was proposed by Messrs. Hull and Green ; the rock forms the high table-land of Kinder Scout, in the Peak country, where the disintegration of the quartzose conglomerate yields numbers of quartz pebbles.

FIG. 10.

The Peak Table-land, Derbyshire.[1]

(Messrs. E. Hull and A. H. Green.)



1. Kinder Scout Grit.
2. Upper Yoredale Shale.
3. Yoredale Grit.
4. Lower Yoredale Shale.

In Lancashire the Millstone Grit contains thin coals, and is estimated to have a thickness of from 3,500 to 5,000 feet.

[1] This section is borrowed from Mackintosh's *Scenery of England and Wales*, p. 214.

In Leicestershire the thickness is 50 feet; it consists in the lower part of quartzose conglomerate, in the middle of grits worked for millstones, troughs, and building-purposes, and in the upper part of grits and shales, which pass by almost insensible gradations into the Coal-Measures above. Sections of this passage are mentioned by Prof. Ansted as visible near Castle Donington and Thringstone.

In Monmouthshire the beds consist of hard sandstone and conglomerate, with shale partings, and have a thickness of 330 feet. In the Forest of Dean the thickness is 450 feet.

In the southern part of Glamorganshire, the Millstone Grit forms elevated ridges of quartzose conglomerate and grit, large blocks of which lie strewn over the surface of the country.

In the Mendip country sections are rarely seen: the beds are generally represented by close-grained quartzite with iron-stained spots.

In Devonshire the Millstone Grit has not been distinguished, although no doubt represented in the lower part of the Culm-Measures,—perhaps by the Coddon Hill Grits.

The Millstone Grit is generally very unproductive and barren, so far as the soil is concerned.

Good building-stones are furnished by the series in Yorkshire, Lancashire, and Derbyshire.

Amongst the stones of local repute may be mentioned the Prudham stone, near Hexham; the Shawbank stone, Stenton Quarries, Barnard Castle, Durham (building); Bramley Fall Grit, Horsforth sandstone, near Leeds; Delph stone, Pule Hill Grit, Yorks.; Parbold stone, Haslingden Flags, Lancashire; the stone from Duffield Bank Quarry, Derby; Darley Dale sandstone, Bakewell; Sydnope stone, near Matlock; Chevin stone, near Belper; Hartshill stone (hard quartzose rocks, altered Millstone Grit), near Nuneaton, Warwick.

COAL-MEASURES.

The Coal-Measures consist of a series of shales, grits, sandstones, and ironstones, characterized by the abundance of coal-seams and the general absence of limestones.

The strata usually occur in what are termed 'Basins:' that is, in synclinal areas or troughs: these basins, however, are not the areas of deposition, but are caused by disturbances and by denudation of the Coal-Measures, which in many tracts were no doubt formerly connected.

The total thickness of the Coal-Measures varies. It is seldom, perhaps never, that we obtain the full thickness, because great denudation has in nearly all cases affected the strata: in some instances, however, the Permian beds are said to rest conformably upon them. In South Wales the total thickness of the series has been reckoned at from 10,000 to 12,000 feet.

Estimating the increase of sediment at 2 feet a century, and admitting with Mr. C. Maclaren that it might take 1,000 years to form a bed of coal one yard in thickness, Prof. Hull has calculated that the deposits forming the South Wales Coal-field might have been accumulated in 640,000 years.

COAL.—Coal is not, strictly speaking, a mineral, being of organic origin; but it is nevertheless frequently classed as such amongst the Hydrocarbons. It is composed of vegetable matter, which through chemical change and pressure, as well as from original decomposition, has lost much of its structure. Amongst the conspicuous kinds of plants which helped to form it, are Ferns, Equisetaceæ, Giant Club Mosses, and Conifers.

Sir William Logan first pointed out (upwards of 30 years ago) that every coal-seam in the Great South Wales Coal-field rested upon a bed of clay, called 'underclay,'[1] which was

[1] In Yorkshire this is generally called 'spavin;' and in Lancashire, 'warrant' or 'seat earth.' (Green.)

penetrated by the roots of *Stigmaria*, and evidently formed the soil upon which the plants originally grew. This fact has been found to be generally applicable in all our coal-fields.

The physical and palæontological evidence prove that the Coal-Measures were formed in an area undergoing slow and gradual subsidence, during which pauses occurred which are marked by the different beds of coal. These seams of coal can sometimes in limited areas be correlated, but looked at in a large way it is scarcely possible to indicate the extent of any one particular seam.

That the beds were mostly deposited in a freshwater and fluvio-marine area is proved by the organic remains; at the same time in some localities there are indications of purely marine accumulations. The conditions presented were probably those of an inland sea, bordered by swamps, into which several rivers brought and deposited sand and mud. The coal-beds which indicate a luxuriant vegetation, were formed when either an increase of sediment or a slight elevation produced a land area. Many remains of plants were, however, drifted, although not very far. The cypress swamps of the Mississippi and the Great Dismal Swamp of Virginia appear to furnish the nearest analogues to the conditions prevailing in Coal-measure times.[1]

There is still a great difficulty in accounting for the purity of Coal, and its general freedom from foreign materials. If, however (as Mr. Henry Woodward has pointed out), we picture a vast alluvial plain covered with a Cryptogamic forest of giant Lepidodendra and Sigillariæ growing on a stiff tenacious clay-soil, capable of retaining the rain-fall, then we have the conditions suited for the rapid production of peat; and that is the purest form we know of any great accumula-

[1] See *Lecture on Coal*, by A. H. Green. (Manchester, 1871.)

tion of vegetable matter *unmixed* with foreign material, which is the peculiar feature of the Coal-measures.[1]

The principal varieties of coal are as follows:—

Anthracite or *Stone-coal*, which has a shining conchoidal fracture, does not ignite so readily as other kinds of coal, and has a much larger percentage of carbon. It is sometimes described as non-bituminous, and has probably been altered by pressure. *Culm* is a variety of Anthracite.

Bituminous coal, which is so called because it has a 'more flaming character in burning than anthracite.' 'The varieties generally recognised are mostly named after their application or chief properties: Free-burning, steam- or smokeless coal, non-caking coal. These, in different grades, approach towards the anthracites, and are chiefly valued for engine and smelting purposes. They often exhibit, in parts of the seams at least, a peculiar fibrous structure, passing into a singular toothed arrangement of the particles, called *cone-in-cone*, or *crystallized coal*.' (Smyth.)

Caking coals are 'bituminous' coals, which are generally used for household purposes, having a tendency to cake, emitting jets of gas and giving off much flame and smoke.

The '*Smalls*' have the property of fusing together in large masses when duly heated, whence they are turned into coke for iron-smelting and for burning in locomotives.

Cannel (*candle*) *coal* is a hard, dull, and clean coal, which readily ignites with a yellow flame, and is much used for gas-making. *Splint coal* has a slaty structure. There is also a variety called '*Peacock coal*,' which exhibits iridescent colours. The term '*Mother of Coal*' is applied to the soft mineral charcoal occurring between brighter laminæ of coal.

[1] *Geol. Mag.*, vol. viii., p. 500. See also Carruthers, *Ibid.*, vol. vi., p. 289.

Different seams are thus suited for different purposes—for smiths, steam, gas, or the household.[1] They vary in thickness from an inch to thirty feet.

Coal has been worked in England since the thirteenth century. In 1259 Henry III. granted a charter to the freemen of Newcastle-on-Tyne for liberty to dig coals. Coal, however, had been known many years before the Christian Era; it was known to the Ancient Britons and to the Romans.[2]

There are two systems of working the coal, termed respectively the 'Pillar and Stall,' and the 'Long Wall' systems. In the former case the coal is worked out in square galleries called stalls, while pillars or posts of coal are left to support the roof: in the latter case long galleries are driven to the full extent of the mine, and the coal is then worked out as far as possible in the intermediate spaces. The latter plan is usually adopted in working thin coals.

The deepest mine in England is at Rose Bridge, near Wigan, 815 yards.

Much danger arises in the mines from the escape during the working of the imprisoned gas called 'fire-damp' (carburetted hydrogen), which is highly explosive when mixed with air, and when ignited produces the much dreaded 'choke damp,' or 'black damp' (carbonic acid gas); so that a good system of ventilation and the use of the Davy lamp are very necessary. In some few districts, as near Radstock in the Somersetshire Coal-field, 'fire-damp' is unknown, and the miners work with naked candles.

Amongst the fossils of the Coal-Measures may be mentioned the following:—Plants, *Sigillaria*, with its root *Stigmaria*, *Lepidodendron*, *Calamites*, *Asterophyllites*, *Alethopteris*, *Pecopteris*, *Neuropteris*, *Sphenopteris*; Mol-

[1] For details on the subject of coal, and the method of working it, see Smyth, *Coal and Coal Mining*.

[2] See Hull's *Coal-Fields of Great Britain*.

luscs, *Aviculo-pecten papyraceus*, *Spirifer*, *Productus*, *Goniatites Listeri*, *Anthracosia*, *Anthracomya*, *Lingula squamosa;* Annelide, *Spirorbis carbonarius;* Crustacea, *Anthrapalæmon*, *Eurypterus*, *Prestwichia*, *Bellinurus*, *Dithyrocaris;* Insects, Myriapods, and Arachnida; Fishes, *Megalichthys*, *Rhizodus*, *Palæoniscus*, and *Cœlacanthus*; and upwards of 30 Labyrinthodont Amphibia.

The term coal-field is applied to the several geographical areas over which the coal-measures are exposed, including the area they occupy beneath newer strata, where they are so connected as to form one field; but many of the different coal-fields may be connected at great depths beneath newer strata.

The largest coal-field in England and Wales is the Great South Wales Coal-field, comprising strata reaching a thickness of upwards of 10,000 feet, and forming an area of 900 square miles. The total area of the coal-fields in England and Wales is estimated at about 3,000 square miles.

[N.B.—For a great part of the following details referring to the Coal-fields, I am indebted to the 'Coal-fields of Great Britain,' by Professor Hull, to which work the reader may refer for more information.]

The coal-fields of England and Wales are as follows:—

1. *Northumberland and Durham Coal-field.*

The strata are thus divided:—

Upper Coal-Measures with thin coals and a band of Ironstone, 900 feet.

Middle Series, from the High Main Coal to the Brockwell Coal, 2,000 feet.

Lower Coal-Measures, with 2 beds of coal, between 2 and 3 feet thick, 150 feet.

The High Main or Wallsend[1] seam (6 feet) is the most noted. The coal-field is traversed by several basaltic dykes, which alter the seams.

2. *Whitehaven* or *Cumberland Coal-field.*

The following divisions are made in the rocks of this tract:—

Upper.—Red Sandstones of Whitehaven, 100 to 150 feet.

Middle.—Developed at Cleator Moor, containing 7 workable coal-seams.

Lower.—Containing 4 or 5 thin and inferior coal-seams.

The seams vary from 2 to 5 feet in thickness. It has been a matter of some dispute whether the Whitehaven sandstone should be classed as Permian or as Coal-Measures.

3. *North Lancashire* or *Ingleton Coal-field.*

The tract of Coal-Measures near Ingleton is but little known and is much obscured by drift beds. It contains some beds of coal, 1 to 9 feet in thickness.

4. *South Lancashire Coal-field.*

This important coal-tract, including the coal-fields of Chorley (Coppul district), Burnley, and Manchester; a small tract in Cheshire near Stockport, sometimes called the Cheshire Coal-field; and the district of St. Helen's, Wigan,

[1] The term 'Wallsend' is now-a-days indifferently applied to coal from various localities, which, however, furnish that best adapted for household purposes. The term 'was originally descriptive of the coal drawn from the spot where the old Roman wall ends on the northern side of the Tyne.'

Bolton, Rochdale, Oldham, and Staleybridge, admits of the following divisions (Hull):[1]—

Upper.—Shales, sandstones, and limestones with *Spirorbis*, fish remains, &c. Thin coal-seams. 1,680 to 2,000 feet.

Middle.—From the Worsley Four-feet Coal to the Arley Mine, 3,000 to 4,000 feet.

Lower or *Gannister Beds*.—Flags, shales, and thin coals, with Gannister floors and roofs of shale, 1,400 to 2,000 feet.

The terms Arley Mine, Mountain Mine, &c., are applied to seams of coal. The seams worked vary from 2 to 9 feet in thickness.

The Riddle Scout Rock (flagstone), the Old Lawrence Rock (flagstone), the tilestones of Dineley Knowl, and the Woodhead Hill Rock (hard flaggy sandstone), are locally known in the Lower Coal-Measures.

The Ardwick limestone is a bed locally known in the Upper Coal-Measures of Manchester.

5. *South Yorkshire, Derbyshire, and Nottinghamshire Coal-field.*

The strata are thus divided:—

Middle Coal-Measures, more than 3,000 feet.

Lower Coal-Measures or Gannister series, including the Penistone flags, the flagstones of Wingfield Moor, and the Gannister Coal group, 700 to 1,500 feet.

The seams vary from 2 to 9 feet in thickness. 'In Derbyshire,' to quote Prof. Hull, 'the principal coals are the "Top hard" and "Lower hard" seams, producing the valuable splint-coal, the "Upper soft" and "Lower soft" coals; and

[1] The Burnley Coal-field is a detached basin on the north: the Cheshire Coal-field is an off-shoot to the south.

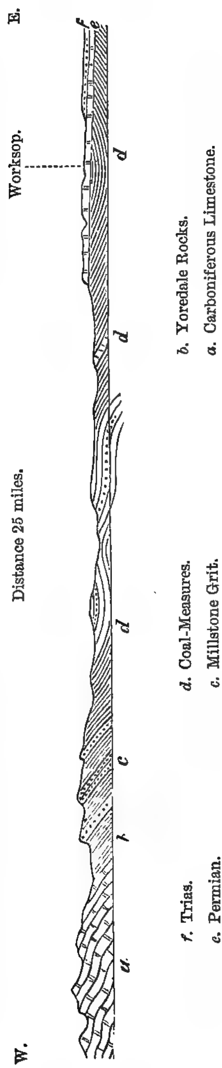


FIG. 11.—*General section across the Derbyshire and Yorkshire Coal-field.*

(Prof. E. Hull.)

Distance 25 miles.

in Yorkshire the most remarkable are the "Silkstone" and "Barnsley thick coals." The former is undoubtedly identical with the "Arley Mine" of Lancashire.'

Clay Cross, near Chesterfield, is a well-known locality in this coal-field. The Honeycroft limestone is a local bed in the Derbyshire Coal-Measures.

Near Penistone the Penistone Flags, the Grenoside Rock and Greenmoor Rock (fine-grained sandstone) are local terms for beds in the Lower Coal-measures, which furnish flagstones and building material.

The Gannister is a hard, fine-grained siliceous sandstone, used for road-metal, and when ground down and mixed with fireclay it makes excellent fire-bricks, or forms a good fire-resisting lining for the inside of furnaces. (Green.)

6. *Ashby-de-la-Zouch* or *Leicestershire Coal-field.*

There are four separate divisions of the Leicestershire Coal-field, three of which only are productive. Of these three, two are on the east and one on the west side of Ashby respectively; that on the north-east being spoken of as the Coleorton, and that on the south-east as the Ibstock and Bagworth Coal-field. The district to the west is the Moira Coal-field. The intermediate district near Ashby contains the lower beds of the series, which are unproductive. (Ansted.)

The following divisions are made in the strata :—

Middle Coal-measures with about 20 coal-seams, of which 10 are workable, 1,500 feet.

Lower Coal-measures (unproductive), 1,000 feet.

The seams of coal vary from 3 to 9 feet in thickness.

7. *Warwickshire Coal-field.*

This tract of Coal-measures extends between Tamworth and Nuneaton, and has been divided as follows :—

Sandstones and shales, at the base of which is a band of limestone, with *Spirorbis carbonarius*, 50 feet.

Coal-Measures with five workable coals (1 seven-feet seam) lying near the centre of the series, 1,400 feet.

Lower coal-measures, unproductive of coal and traversed by dykes of greenstone, 1,500 feet.

8. *North Staffordshire Coal-field.*

The strata in this Coal-field (the Potteries), including that of Cheadle, have received the following divisions:—

Upper.—Brown sandstones, greenish conglomerate with thick beds of red and purple mottled clays; thin coals, and a bed of limestone ('Spirorbis limestone') at Fenton, 1,000 feet.

Middle.—Sandstones, shales with ironstone, and about 40 coal-seams, 4,000 feet.

Lower.—Black shales and flags, with Wetley Moor thin coals, and the red ironstone of the Churnet Valley, 1,000 feet.

There are seams from three to nine feet in thickness.

9. *South Staffordshire Coal-field.*

The beds comprise:—

Upper Coal-measures, 1,300 feet, consisting of red and mottled clays, red and grey sandstone, &c.

Middle Coal-measures, coals, ironstone, &c., 510 feet.

The most remarkable seam in the Dudley district is the 'Ten yard' or 'Thick coal,' which has a general thickness of 30 feet.

Cannock Chase and Walsall are localities of importance in this coal-field; and the Rowley Rag basalt is well known in connection with the district.

10. *Shropshire Coal-field.*

The Shropshire Coal-field may include the three fields of the Forest of Wyre, the Shrewsbury Coal-field, and the Coalbrookdale Coal-field. Two outlying tracts of coal-measures occur on the Titterstone and Brown Clee Hills which are capped by hard basalt.[1]

In the Coalbrookdale Coal-field there appears to have been some denudation of the Lower Coal-Measures before the uppermost strata were deposited.

The seams vary from 1 to 6 feet in thickness.

In the Upper Coal-Measures of the Forest of Wyre, and in the Shrewsbury Coal-field, there occur 2 beds of limestone from 3 to 7 feet in thickness, containing *Spirorbis carbonarius* (an annelide), and called the 'Spirorbis Limestone.'

'The coal band in the Abberley Hills is placed between the Permian or else New Red conglomerates and the Old Red marl series. It is in reality conformed to neither, nor, as in the more frequent exposures of coal between the Old and New Red near Newent, is there any semblance of conformity to the older deposit. It is of no commercial value; nor is the value considerable of the small tract of coal lying on Old Red, north of the Abberley Hills.' (J. Phillips.)

11. *Forest of Dean Coal-field.*

The Coal-measures in this district attain a thickness of 2,765 feet, and contain 15 seams, of which 8 are of a thickness of 2 feet and upwards. The thickest seam is about 5 feet.

There is a remarkable instance of what is called a 'horse' in this coal-field, which according to De la Beche resembles

[1] These include the little coal-fields of Cornbrook, Newberry, and Billingsley.

a channel cut amongst a mass of vegetable matter: in fact it appears to be an old river-channel filled with mud.

Mr. R. Gibbs has stated that along the south-west side of this Coal-field, the Millstone Grit and Carboniferous Limestone are overlapped unconformably by the Coal-measures.

12. *Bristol and Somerset Coal-fields.*

Upper Series	*a.* Radstock, &c. *b.* Farrington Gournay, &c.	Sandstones, shales, and coal. 2,000 feet.
Pennant Grit.	Chiefly sandstone.	2,000 feet.
Lower Series	*a.* Kingswood, &c. *b.* Vobster, &c.	Sandstones, shales, and coal. 2,500 feet.

Three Coal-basins are exposed at the surface, that of Bristol and Radstock, the little faulted tract of Clapton-in-Gordano, and that of Nailsea. One other has been proved in the bed of the Severn, and this may possibly be connected with the Clapton Coal-field.

While to the south of the Mendips beneath the flats of Sedgemoor there is very little doubt that another Coal-tract exists. (See fig. 8, p. 84.)

The eastern limits of the Coal-basin to the north of the Mendips may be pretty well defined, but those of the probable basin to the south can scarcely be more than guessed at. Further, it is a fertile topic for speculation whether other basins may not continue beneath the Secondary rocks to the east, even so far as London and the Eastern and South-eastern counties.

The productive Coal-measures are separated into an upper and lower series by the beds known as Pennant Grit. These grit-beds are much used for building purposes. In the Bristol district they include the Holmes Rock, formerly classed as Millstone Grit.

The seams of coal worked are often very thin, being near Radstock from one to three feet in thickness.

The Radstock district is noted for the variety and preservation of the fossil plants.

13. *North Wales Coal-fields.*

The Coal-measures of North Wales are separated by an extensive fault into two tracts, respectively called the Flintshire and Denbighshire Coal-fields.

The general thickness in the Denbighshire Coal-field is as follows:—

Upper series,	1,000	feet.	
Middle ,,	800	,,	with coals.
Lower ,,	1,000	,,	with thin coals.

In Anglesea a little tract of Coal-measures is preserved, owing to a great fault, which has a downthrow of upwards of 2,000 feet. The Coal-measures attain a thickness of over 1,300 feet, and contain seams from one to nine feet in thickness.

A small patch of red unproductive Coal-measures rests on the limestone opposite Caernarvon. A band of unproductive Coal-measures forms a narrow strip of coast-line between Caernarvon and Llanfair-is-gaer, and is succeeded by a belt of Carboniferous Limestone from thence to Gored-girth on the coast near Bangor. (Ramsay.)

In the Denbighshire Coal-field the Coed-yr-allt rock, 30 to 60 feet in thickness, a greenish-white and grey sandstone, belonging to the Upper Coal-measures, has been quarried. The Newbridge shales and Cefn freestone are terms locally applied to strata of the Upper Coal-measures in this district. These rocks have been described by Mr. D. C. Davies, who has drawn attention to the occurrence of coal-seams in supposed Permian beds near Ifton, Shropshire.

14. *South Wales Coal-field.*

The following general succession of the Coal-series has been given by Prof. Hull:—

Upper Pellengare series, consisting of sandstones, shales, and 26 coal-seams, more than 3,400 feet in thickness.

Pennant Grit, hard and thick-bedded sandstones, with 15 coal-seams, 3,246 feet in thickness. Cock-shoot rock at base.

Lower Coal-measures or White Ash Series, principally shales, rich in ironstone, 34 coal-seams, 450 to 850 feet in thickness.

Millstone Grit, represented in the south by the Gower Series.

The Lower Coal-measures form the iron-bearing strata at Merthyr Tydvil, and the Taff Vale.

In Monmouthshire the thickness of the Coal-measures is given at 11,650 feet by Prof. Hull, including the Gower Series above the Millstone Grit.

The total thickness of all the coal-seams taken together has been estimated at 120 feet: they vary in thickness from three to nine feet.

15. *Devonshire Culm-Measures.*

The Coal-measure rocks of Devonshire can only for the sake of convenience be grouped with those of other parts, for they certainly form a very unproductive series so far as coal is concerned.

The term Culm-measures was applied to the 'Carbonaceous' rocks of Devonshire on account of the workings for Culm near Bideford and other places.

Looked at in a large way, they consist of a series of shales, grits, chert-beds, with beds of limestone here and there.

The series occupies a trough between the Devonian rocks of North Devon and West Somerset and those of South Devon and Cornwall. The beds may therefore be said to occupy a basin or synclinal, but they exhibit in themselves great undulations and contortions (so well seen in the cliffs at Clovelly and along the coast), and as they have not yet been worked out in detail, any estimate of their thickness must be very vague.

Some authorities have placed them, generally, on the horizon of the Millstone Grit, but there seems to be good reason to include with them representatives of at least a portion of the true Coal-measures, and possibly also of the Carboniferous Limestone.

The beds pass imperceptibly downwards into the Upper Devonian strata of North Devon; in South Devon, however, this conformability has been disputed, but owing to the numerous faults and other disturbances the exact relations have not been satisfactorily determined, and this can only be done by minute survey.

The series of carboniferous deposits in (1) North Devon, about Barnstaple and Bampton, is thus given by Prof. Phillips:—[1]

> Upper part, anthracitiferous, and containing ironstone, and by these characters agreeing with the coal-deposits of Pembrokeshire. This is in general a gritstone series, with plants of the coal formation.
>
> Coddon Hill cherts, black grits, jasper rock, lydian stone, and shales of considerable but variable thickness; 1,500 to 2,000 feet according to the Rev. D. Williams.

[1] See also Holl, *Quart. Journ. Geol. Soc.* vol. xxiv. p. 400.

Limestone and black shale, with *Posidonomya*, *Goniatites*, &c. = *Posidonomya* (*Posidonia*) *limestone* of Swimbridge and Venn.

Black shale group.

(2) The South Devon strata about Trescott and Lew Trenchard have been thus divided:—

Gritstone group of Central Devon.

Upper shale group—dark shales, carbonaceous grits and shales, equal to the Coddon Hill series.

Calcareous group—limestone of dark colour, and irregular bedding, with shales (*Posidonomya*).

Lower shale group, with few fossils. (No slaty cleavage.)

The Culm-measure series is characterized by beds of greenish-grey grit, black-looking shales, sometimes cleaved, and occasional beds of quartzose conglomerate. The beds of grit are sometimes sufficiently developed to be useful for building purposes, as near Chudleigh, while flagstone beds are worked near Launceston. The Grinshill freestone has been worked near Bideford.

The researches of Sedgwick and Murchison tend to show that although this overlying series is in mineral aspect as much unlike the Carboniferous strata of most other parts of Britain, as the rocks of North Devon are unlike the ordinary Old Red Sandstone of England and Scotland, yet there are proofs by fossils, besides the analogy with Pembrokeshire, that the black limestones of Swimbridge and Venn, &c. with *Posidonomyæ* represent, on a miniature scale, a part of the Carboniferous Limestone; that the next series of white grit and sandstone of Coddon Hill, &c. stands in the place of the Millstone Grit; and that the overlying courses of culm, grits and shales, with many remains of plants, are the equivalents of the lower coal-bearing strata. At the same time it must

not be overlooked that beds lithologically identical with Old Red Sandstone occur at the base of the Devonian series in North and South Devon, and that the upper portion of this series may represent some of the Lower Carboniferous rocks.

The Black or Culm-limestones occur at Bampton, Holcombe Rogus, Canon Leigh, and West Leigh, where the beds are often very much disturbed and even violently contorted. They are also met with at Drewsteignton, and near Launceston.

The Culm-limestone according to Sedgwick and Murchison often appears to come to an edge or to pass into calcareous shale.

In the large quarries seldom more than a third or fourth part can be burnt for lime: the alternating bands of dark indurated shale are used for flagstones or coping-stones.

The base of the Culm-measures, particularly between Barnstaple and South Molton, is noted for the occurrence of Wavellite (hydrous phosphate of alumina), which exhibits its radiating crystals on the broken transverse joints of the slaty rocks: hence the term 'Wavellite schists.'

In places near the granite of Dartmoor the rocks are much metamorphosed, and beds of indurated black slate pass into lydian stone; near Bampton the shales become indurated and cherty.

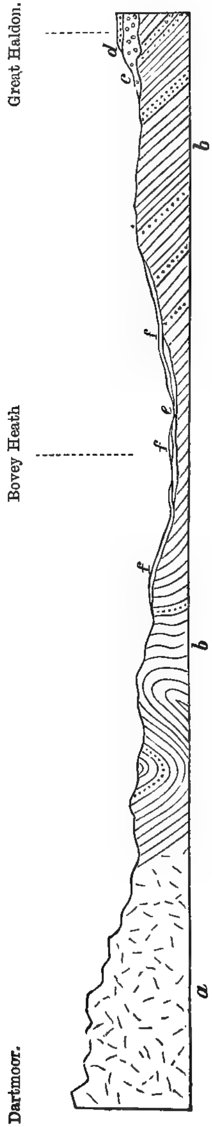
North of Boscastle the beds are traversed by large quartz veins and are violently contorted. According to Sedgwick and Murchison some of the shales are calcareous, and contain masses of a variety of Rottenstone like that in the limestone-shales of Derbyshire.

Mines of Lead, Iron, and Manganese have been opened in different places in the Culm-measures.

The beds of Culm stretch across the country from Barnstaple Bay to Bideford towards Chittlehampton, and they

FIG. 12.—*Section from Dartmoor to Great Haldon.*

Scale = Half-an-inch to one mile.



f. Gravel. d. Upper Greensand. b. Culm-Measures.
e. Bovey Beds. c. Triassic Breccia and Sandstone. a. Granite.

have been worked at different periods, although never with any great profit.

Murchison has observed that the coal-field which is bituminous in Monmouth, Glamorgan, and Caermarthen, becomes anthracitic in Pembroke, where the stone-coal series, much disturbed and broken, differs from that of Devon only in being much more productive. Possibly some of the culm-strata of Devon, devoid as they are of any workable coal, may yield bituminous products by the application of heat. Some of the culm-beds of Devon may be considered subordinate to the Millstone grit; but most of the culm overlies that rock, and is simply the equivalent of the culm of Pembrokeshire.

Economic Products, &c., of Coal-Measures.

The Coal-measures form generally an unproductive soil.

The flags and sandstones are extensively quarried for building and paving purposes, and for firestone. Amongst these may be mentioned the Heddon and Kenton Freestone, Newcastle; Catlow stone (laminated flagstone) and Hapton stone (flagstone), Burnley, Rochdale flagstone; Upholland flags (lower coal-measures), used also for grindstones and scythe-stones, Orrel, Billinge Hill and Upholland, Lancashire; Peel stone, near Bolton; Thwaites Delf white stone, Wigan; Rushy Park roof-stone, Rainhill and St. Helens. Clay Wood stone,* Slatestone rock * (roofing-slates, paving), Handsworth Bluestone, Brincliffe Blue stone, Brincliffe Edge, used for flags, gravestones, for whitening stones, &c. (lower coal-measures), Lidgate rock, Manor stone (building and flags), Grimesthorpe, Wadsley stone, near Sheffield; Potternewton stone, near Leeds; Yorkshire paving-stone, Bretton quarry, Halifax (lower coal-measures); and the Shepley stone (flags) near Huddersfield.

Near Bradford the Adwalton and Birstal rock, and the Bradford and Elland flagstone, are of economic importance. Some flags of a size twelve feet square have been obtained: thin beds are used for roofing purposes.

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* These are rocks in the Carboniferous Series, but doubtfully referred to the Coal-Measures.

The following rocks are also of Carboniferous age:—Shaw Lane stone,* Belper; Wingerworth stone, near Chesterfield; Freebirch stone, near Chesterfield; Gornal sandstone? * Sedgeley, S. Staffordshire.

The Dean Forest stone is used for building-purposes and grindstones; the Black Pins rock is worked in Ebbw Vale (Lower Coal-measures).

The Clays of the Coal-Measures are used in the manufacture of bricks and tiles, earthenware and pottery: the clays of Stourbridge are noted for the manufacture of fire-bricks, so are some at Newcastle, Bradford, &c.

In Shropshire a red marl from the Coal-measures is employed in the manufacture of encaustic tiles.

In the South Wales Coal-field, near Merthyr-Tydvil, Hatchettine, or mineral tallow, a hydro-carbon, is found.

Near Bradford the Gannister or Calliard stone has been ground to a fine sand to be used in the casting of iron and brass.

Grindstones sometimes called Newcastle grindstones are formed from sandstones from the coal-districts of Northumberland, Durham, Yorkshire, and Lancashire.

At Bilston, in Staffordshire, a peculiar sandstone is found lying above the coal, finer than the above, and of a very sharp nature. This is quarried entirely for the *Bilston grindstones*, which are of great excellence.

The *carpenter's millstone* is a hard and close variety of the Yorkshire sandstones. The northern counties yield several varieties of grindstones, which are much in request for different descriptions of work. *Yorkshire grit*, for example, is used for polishing marble and the copper plates for engravers. The *Sheffield grindstone* is a hard and coarse stone used for common purposes: it is found at Ardsley, 14 miles north of Sheffield. The *Sheffield blue stone* is a fine-grained stone, used for finishing fine goods. The act of grinding on a blue stone is termed '*whittening*'—the

* See note on p. 111.

Sheffield whittle from the earliest periods being in all probability ground on this stone. *Wickersley stones* are obtained about nine miles from Sheffield, and are much used by the cutlers for grinding.[1]

In the lower beds of the Coal-measures near Bradford, iron-pyrites has been worked for the manufacture of sulphuric acid and sulphate of iron.

The Clay-ironstone of the Coal-measures yields much of the iron in this country. Petroleum springs have been met with in the Coal-measures near Broseley; one called the 'Burning Well' existed about a century ago.

Supply and Duration of Coal.—The subject of our supply of coal has been exhaustively treated in the Reports of the Royal Coal Commission. It appears that there is a quantity of Coal in England and Wales in the visible Coal-fields, available at a depth not exceeding 4,000 feet, equal to upwards of eighty thousand millions of tons; whilst the amount of coal similarly available beneath the Permian and newer strata, is estimated at about fifty-six thousand millions of tons. The probable duration of our supply is variously estimated, but that it is considered good, at depths readily accessible, for at least 276 years is satisfactory.

[1] Hunt and Rudler, *Descriptive Guide to the Museum of Practical Geology.*

SECTION II.

SECONDARY OR MESOZOIC.

Chapter V.

POIKILITIC.

Compared with the Palæozoic rocks, the Secondary strata form a very distinct group. The beds, although well consolidated, are yet, on the whole, free from the striking signs of alteration or metamorphism which are so largely present in the older rocks. The lines of stratification are marked and easily recognizable, and the beds have suffered but little from the effects of great disturbance which are so conspicuous in the deposits of earlier times.

Although in some localities an apparent passage has been observed of the Permian beds into Coal-measures, yet on the whole the Secondary strata lie unconformably upon the denuded Palæozoic rocks. Lyell has well remarked, 'that nowhere have geologists found more difficulty in drawing a line of separation than between the Secondary and Primary series,' for indeed there is no great break between them.

The Secondary rocks are characterized by Marsupial Mammalia; by numerous remains of Reptilia, such as the *Ichthyosaurus* and *Plesiosaurus;* by Mollusca, of the genera Ammonites, Belemnites, Trigonia, Rhynchonella, and Terebratula; by Corals, and by Cycadeiform plants.

POIKILITIC.

The Permian and Triassic beds have been very differently classed by geologists, because the strata taken as a whole form a connecting link between the Palæozoic and Mesozoic periods.

Thus, whilst the fauna and flora of the Permian rocks unite them more closely to the Palæozoic rocks than to the Trias, in their lithological characters and in the evidences of their method of formation, the two groups seem inseparably connected, and with them the Rhætic or Penarth beds may very conveniently be classed.

On geological maps the group forms a conspicuous band, stretching across England from the mouth of the Tees to the mouth of the Exe, with a branch running to the mouth of the Mersey: thus marking off the Palæozoic ground of the north of England, of Wales, and of the S.W. of England, from the Secondary and Tertiary tracts, which lie to the south-east.

The Permian and Triassic rocks, from their prevailing red colour, are equally prominent, and the 'red ground' and 'red rocks' have given many a name to our hamlets, villages, and towns, such as Rotherham, Retford, Radford, Radcliffe, Radstock, &c.

The term New Red Sandstone was originally used to distinguish these strata from the Old Red Sandstone.

In their general lithological characters there is a marked similarity throughout the Permian and Triassic series, consisting as they do of red sandstones, conglomerates, and marls, with occasional beds of limestone. Originally, the whole of these rocks were classed as New Red Sandstone, and the name 'Poikilitic' (meaning *variegated*), subsequently suggested by Conybeare as an equivalent term, is one that possesses many advantages to recommend it.

On physical grounds Sedgwick classed the Permian series with the Trias.

There are instances in Lancashire, Cheshire, and Derbyshire, where a kind of gradation appears between the Coal-measures and the Permian sandstones, which are locally conformed to them; near Coventry the Permian beds appear conformable to the Coal-measures, and to be overlaid unconformably by the Trias; and in East Yorkshire there is considerable similarity between the beds at the base of the Permian series and those at the top of the Coal-measures, and the beds have been differently classified in places by geologists.

Professor Hull, however, believes that there is an unconformability between the Permian and Carboniferous rocks in Lancashire and Yorkshire.

It is considered by some observers that the different members of the Permian formation are not strictly conformable to one another. A most decided instance of unconformability is stated to occur in the railway-cutting at Tadcaster. 'The Middle Marl has there thinned away to a mere seam, so that the Upper Limestone rests almost directly on the Lower, and at the base of the former there is a thin bed of gravel formed of Lower Limestone pebbles.' [1]

In isolated masses, as might be expected, it is not always easy to distinguish between the Permian and Triassic beds. Thus certain red sandstones in Lancashire, referred to the Permian period by Mr. Binney, have been considered as Bunter by Professor Hull; although the latter admits that, 'isolated as the beds are here, there can be no certainty regarding their age.' In some parts of Yorkshire, the Permian seems to pass upwards into the Trias.

The Rev. A. Irving has remarked that there are clear signs of continuous deposition of the Permian and Lower

[1] Explanation of Quarter Sheet 93 S.W. (*Geol. Survey*).

Bunter rocks in Nottinghamshire; and, so far as that area is concerned, the stratigraphical data seem to point to the conclusion that the Permian and Bunter are but portions of one great unbroken sequence of rocks.

In treating of the physical history of the Permian and Triassic rocks of Great Britain, Professor Ramsay has pointed out that the beds were deposited in great inland lakes for the most part salt. One objection might be taken to this theory, inasmuch as the organic remains of the Magnesian Limestone are truly marine types. Professor Ramsay, however, observes that these are wonderfully restricted when compared with those of Carboniferous times, and in the poverty and dwarfing of the forms the fossils of this rock may be compared with the still less numerous fauna of the Caspian; so that he considers they might have lived similarly in a large inland salt lake which had previously been connected with the open ocean.

PERMIAN.

Magnesian Limestone Series.

The name Permian was proposed by Murchison in 1841, from the ancient kingdom of Permia, in Russia.

The Permian rocks consist of red sandstones, conglomerates, marls, and magnesian limestones, of which the following series is generally established :—

			Yorkshire
Upper Permian or Magnesian Limestone Series (Zechstein).	Red Sandstone and Marl. Magnesian Limestone. Marl slate.	or	Upper Red Marl and Sandstone. Upper Magnesian Limestone. Lower Red Marl and Sandstone. Lower Magnesian Limestone.
Lower Permian (Roth-liegende).	Lower Red Sandstone, Marl, Breccia, and Conglomerate.		

The fossils are generally met with in the Magnesian Limestone or Marl slate; plant remains, however, are found in the Lower Red Sandstone: they include *Fenestella retiformis*, *Productus horridus*, *Spirifera alata*, *Avicula speluncularia*, *Schizodus obscurus*, *Bakevellia*, *Palæoniscus*, &c.; also remains of *Protorosaurus* and Labyrinthodont reptiles. The flora, which includes *Sigillaria*, *Alethopteris*, and *Neuropteris*, is nearly allied to that of the Coal-measures; but Mr. Carruthers has observed that the Permian vegetation possesses Mesozoic affinities, and in fact that the commencement of the Mesozoic flora is to be sought in the Permian.

Professor Phillips first suggested that the Magnesian Limestone should on palæontological grounds be classed as Palæozoic.

The following localities where the beds are represented are given by Murchison:—

Red Sandstone and Marl.—West of Doncaster; St. Bee's Head and Corby Castle, Cumberland.

Magnesian Limestone.—Coast Cliffs from Tynemouth to Hartlepool, Clacksheugh, Eldon, Thickley, Ferry Hill, Humbleton Hill (Durham); Masham, Roach Abbey, Bramham Moor, Ferrybridge, Tadcaster, Knaresborough, Bolsover Moor, Creswell Crags (100 ft.), and Steetly (Yorkshire, Derby, and Notts.)

Marl Slate.—Thickley, Ferry Hill, Durham; Escarpment of Magnesian Limestone from Bramham Moor to Nottingham.

Lower Red Sandstone, &c.—Clacksheugh, Durham; Plumpton Rocks, near Knaresborough, and Pontefract, Yorkshire; Astley, Lancashire; Penrith; Wolverhampton to Coalbrook Dale, South of Shrewsbury, West of Birmingham, and around the Dudley Coal-field.

This statement will explain the use of some local names, such as the Pontefract rock (W. Smith), which forms a natural base to the Magnesian Limestone; the Bolsover Limestone, which is a yellowish-brown dolomite; the Knottingley Limestone, the Weldon Wood Stone near Ferrybridge, the Fulwell Limestone near Sunderland, &c.

The lower portion of the Plumpton rocks has been considered by some geologists to be Millstone Grit (see p. 90.)

In Durham the thickness of the Permian rocks is about 600 feet.

Lower Permian Beds.—Professor Hull has pointed out that the Lower Permian series of the western and central parts of England may be arranged under two distinct types of strata, of which those at Enville in Shropshire, and the sandstone of Collyhurst, near Manchester, may be considered as representative beds. To the Salopian type may be referred the whole of the Permian rocks as they occur in Shropshire, Staffordshire, and Warwickshire; and to the Lancashire type, the rocks of this formation as they occur at Stockport in Cheshire, in South Lancashire, and the north-west of England.

The beds of the Salopian type attain a thickness of about 1,500 feet, and include:—

Red and purple sandstones and marls; breccia, calcareous conglomerate, sandstone and marl; purple, red, brown and white sandstones, often calcareous.

The beds of the Lancashire type include:—

Red marls with numerous bands of fossiliferous limestone, worked for lime, 130 feet. (These beds are considered to be the representatives of the Magnesian Limestone of Yorkshire and Durham.)

Bright red and variegated sandstone, about 1,500 feet.

The evidence furnished by these types led Professor Hull to conclude that a ridge of Lower Carboniferous rocks crosses the plain of Cheshire beneath the Trias, and forms a boundary between them.

Magnesian Limestone.[1]—The Magnesian Limestone is sometimes globular or botryoidal in structure; it is usually of a yellowish colour, and sometimes contains cavities lined with crystals of calc spar. In composition it contains nearly equal proportions of the carbonates of lime and magnesia: and it is sometimes termed Dolomite or Dolomitic limestone.[2]

The dolomitic limestone of Marsden, near Sunderland, is flexible. Some beds in Yorkshire are said to be fetid.

The thickness of the Magnesian Limestone is 300 feet in Durham, and this thickness is maintained at Pontefract, the series gradually diminishing in thickness to about 120 feet near Annesley.

The Magnesian Limestone has been largely quarried at Bolsover in Derbyshire, from which locality the stone used in the construction of the new Houses of Parliament was procured. There is about 12 feet of workable stone, of a pale brownish-yellow colour.[3] Southwell Minster was also to some extent constructed from this stone, and partly from that at Mansfield. Quarries have been largely worked at Roach (or Roche) Abbey, near Bawtry, in Yorkshire; also in the neighbourhood of Doncaster, at Brodsworth, and Park-nook, Worksop, &c.

The stone employed in the Museum of Practical Geology was obtained at Anston. At Huddlestone, the rock used in the construction of Westminster Hall was obtained. Jackdaw Craig, near Tadcaster, and Smawse on Bramham Moor,

[1] Termed Redland limestone by Wm. Smith.

[2] So called after the geologist Dolomieu.

[3] Sometimes termed Dunstone in Derbyshire.

are well known localities for this building-stone. York Minster was partly constructed of stone from Jackdaw Craig, and Beverley Minster of stone from Smawse.

The yellow crystalline limestone of Mansfield Woodhouse is well known as furnishing a good building-stone; in the neighbourhood of Mansfield, red and white sandstones, which are probably on the same horizon, and, according to Mr. Aveline, only siliceous varieties of the Magnesian Limestone, have been much quarried for building purposes: they are known as the Mansfield White and Mansfield Red Sandstones. The Mansfield sands have been used for casting. Quicksand occurs at the base of the Magnesian Limestone south of Harthill.

The Magnesian Limestone forms light, arable, and dry soil; it has been used for agricultural purposes, being burnt for manure, the limes of Kinnersley, Knottingley, Roach Abbey, Brotherton, Ferrybridge, Mansfield, &c., being celebrated.

Slabs of Magnesian Limestone are said to have been polished at Knaresborough, Sunderland, &c.

The Lower Magnesian Limestone near Tadcaster contains beds of hard flinty rock, called Calliard or Galliard, which is used for road metal.

In some of the chemical works on the Tyne the dolomites of the northern counties are used for the production of carbonate of magnesia; while the magnesian limestones of Marsden are taken in considerable quantities to Sunderland, where, being treated with sulphuric acid, the magnesia is dissolved out, and from the liquor obtained, Epsom salt (*sulphate of magnesia*) readily crystallizes. A considerable proportion of the Epsom salts now sold is thus obtained.[1]

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[1] Hunt and Rudler, *Descriptive Guide to the Museum of Practical Geology.*

The Permian beds of the Lake district occupy the Vale of Eden or Cumberland Plain, resting unconformably upon the Carboniferous rocks. They also border the sea-shore from St. Bee's Head to the estuary of the Duddon, and occur further south at Walney Island and the adjoining land.

The unconformability is shown near Appleby, and near Whitehaven. Here the beds are well developed. The lower division consists of red sandstones and breccias, including the Penrith sandstones, and also in places magnesian limestone; the middle division consists of red gypseous shales and clays (Hilton shales), with thin limestones; and the upper of red and white sandstones (Corby Sandstones) and shale.

Dr. Nicholson states the maximum thickness of the group to be 8,000 feet in the neighbourhood of Penrith, and from 3,000 to 4,000 feet in the vicinity of Appleby. Professor Harkness considers that there is little prospect of workable coal beneath the Permian beds of the Vale of Eden.

Mr. Goodchild informs me that pseudomorphous crystals of rock salt occur in the marls, and that the Lias and Rhætic Beds come on close above the series at Carlisle: facts suggesting the possibility of some of the so-called Permian turning out to be Trias. The term 'brockram' is locally applied to the breccias, which are formed to a large extent of fragments of Carboniferous Limestone imbedded in a red sandy matrix. They are well developed near Appleby and Kirkby Stephen, and are largely quarried in places for lime.

Some plant-remains, *Alethopteris*, *Cardiocarpum*, *Odontopteris*, *Sphenopteris*, and *Ullmania*, found in the Hilton Shales, are the only organic remains recorded from the Permian rocks of the Vale of Eden.

At St. Bee's Head, the Permian and Trias are considered by some authorities as unconformable. Sedgwick considered the red sandstone to be Bunter.

The following is the section at St. Bee's Head :—

	Feet
Upper Permian or St. Bee's Sandstone.	
Red and green marls with gypsum	30
Yellow magnesian limestone with casts of fossils . .	11
Breccia	3
Whitehaven sandstone (Coal-measures or Permian ?)	

The sandstone of St. Bee's Head was used in the construction of Furness Abbey.

Near Manchester the Permian beds consist of a series of red marls, clays, and sandstones, with bands of fossiliferous limestone, resting upon red sandstones (Collyhurst sandstone) and conglomerates: these again repose unconformably upon the Coal-measures. The thickness is from 100 to 140 feet.

In Durham, the Permian rocks are from 600 to 700 feet in thickness, consisting of the following beds:—

	Feet
Marls with gypsum	100
Limestones (brecciated at Tynemouth Cliff) with molluscan remains	300 to 400
Marl slate with fine specimens of fossil fish .	
Sandstone and gypseous marl, with plant remains .	200

Traces of Permian rocks occur south of Ashby-de-la-Zouch, in Leicestershire; but according to Professor Ansted it is a 'doubtful fragmentary and unimportant deposit.' The beds occur in a gravelly and loose state, so that in one locality the deposit is known as the 'Poxon gravel.' 'It is an interesting fact that the pebbles of the gravel and breccia forming the Permian deposits appear to have come from the west, no trace of Charnwood rocks having been discovered amongst them.'

In Nottinghamshire the following divisions have been made:—

Red Marl and Sandstone.

Red and Purple Marls, with thin bands of Limestone.

Magnesian Limestone.

Conglomerate.

The marls have in places been used for brick-making.

Near Tadcaster, the lower Permian marls have yielded gypsum, formerly worked for Plaster of Paris.

Near Rotherham, beds of red sandstone (Rotherham red rock)[1] are quarried for grindstones and for building purposes; and in the same neighbourhood is found a variety of Raddle or Reddle, much used in polishing lenses, &c. At Harthill, the red sandstone is worked for scythe-stones.

The Alberbury breccia, near Shrewsbury, is probably of Permian age. The conglomerates and breccias of Cumberland, South Staffordshire, Enville, the Lickey and Clent Hills, the Abberley and Malvern Hills are generally rough, coarse, and subangular; the stones and boulders being embedded in a red marly paste. In Professor Ramsay's opinion these are simply old boulder-clays, formed at a glacial period in Permian times.

At the Clent Hills, the Permian breccia is considered to be about 450 feet in thickness.

On the eastern face of the Malvern Hills is a band of brecciated rocks, termed by Professor Phillips the Haffield Conglomerate, which is about 200 feet in thickness.

Near Stafford the red sandstone has been worked for building purposes. In South Staffordshire the thickness of the Permian beds is estimated at from 1,000 to 3,000 feet; and in North Staffordshire from 500 to 700 feet.

In Cheshire the Permian beds attain a thickness of from 600 to 800 feet.

In the Vale of Clwyd traces of Permian beds have been indicated by Mr. Maw as resting on the Carboniferous Limestone, and being overlaid unconformably by Bunter beds.

In Anglesea the Permian beds rest unconformably upon the Coal-measures; they consist of red marls, sandstones, and conglomerates, and attain a thickness of nigh 400 feet.

[1] Some observers have placed this rock in the Upper Coal-measures.

It has been suggested that certain breccias in Devonshire may be of Permian age. (See p. 141.)

TRIAS.

The term Trias has been adopted from the German geologists, being applied to the triple division that may be made in places on the Continent in this series of rocks. These three divisions are (in descending order) Keuper, Muschelkalk, and Bunter. The Muschelkalk, which is a grey shelly limestone, has not been identified in this country, and its absence has led many geologists to regard our Triassic series as incomplete, to identify in it only the upper and lower divisions of the German Trias, and to regard the Keuper as deposited unconformably upon the Bunter. The following shows this classification :—

Trias	Keuper	Red and Variegated Marl.
		Lower Sandstone and Marl (Waterstones).
		Dolomitic conglomerate.
	Bunter	Upper Mottled sandstone.
		Pebble-beds.
		Lower Mottled sandstone.

There seems to be no doubt that in some localities there are evidences of erosion or disturbance between the beds classed as Bunter and those classed as Keuper, but there does not appear to be any satisfactory evidence from which to conclude that such unconformability was produced at one time over the entire British area.

The absence of the Muschelkalk in the British area must not of itself be taken as any evidence whatever of an unconformability, considering the very variable nature of the Triassic strata, and of the conditions under which the beds were deposited in different areas.

The use of the terms Bunter and Keuper is convenient,

although the beds in our country so designated cannot be correlated in time with exactness with the rocks distinguished by those names on the Continent. In the same way, where the Oxford and Kimeridge clays come together without the intervention of the Coral Rag series, and without unconformability, we cannot perhaps identify the exact equivalent of the Coral Rag, and cannot do better than use the purely lithological terms.

Bunter.

New Red Sandstone.

The Bunter (variegated) Sandstone of Germany was first identified in England in 1826 by Sedgwick.

The general divisions of the Bunter beds are thus given by Professor Hull :—

Upper Mottled Sandstone.—Soft, bright, red, and variegated sandstone.

Pebble Beds or Conglomerate.—Harder reddish brown sandstones, with quartzose pebbles, passing into conglomerate; with a base of calcareous breccia.

Lower Mottled Sandstone.—Soft, bright, red, and variegated sandstone, showing much false bedding.

The Lower Mottled Sandstone attains a thickness of about 650 feet at Bridgenorth; in Cheshire it is 400 feet; at St. Helen's Junction it is about 250 feet; and in South Staffordshire 200 feet.

The Pebble beds attain a thickness of from 60 or 80 feet to 600 feet. They are composed chiefly of quartz, the pebbles of which (according to Mr. Aveline) are found either loosely scattered amongst unconsolidated sand, or cemented into a hard conglomerate. So gradually do they pass into

the sandstones below that there is no very definite line of separation.

The Upper Mottled Sandstone attains a thickness varying from 200 feet to as much as 700 feet at Delamere Forest.

The total thickness of the Bunter beds is estimated at 1,000 to 2,000 feet.

The Hemlock or Himlock Stone, near Nottingham, consists of the Lower Mottled Sandstone capped by the Pebble beds. In this locality the sandstone is about 80 feet thick, but further towards Nottingham it has a thickness of 100 feet.

The Vale of Clwyd is formed in the Bunter sandstone, belonging in all probability, according to Professor Hull, to the Lower Mottled Sandstone; but sections are rarely seen owing to the covering of drift. In the Bridgenorth district these beds form the fine ridges of Apley Terrace, Pendlestone Rock, Abbot's Castle Hill, and Kinver Edge.

The beds may also be studied near Market Drayton, Cannock Chase, and Sherwood Forest.[1]

The greater part of Nottingham is built on a coarse white sandstone, containing scattered pebbles of quartzite, &c., belonging to the conglomerate division, according to Professor Hull. The old castle stood on a cliff of the same rock. Artificial caverns have been excavated in it.

In the Liverpool district the beds are represented by reddish-brown pebbly sandstone, largely quarried for building purposes.

The Upper Red and Mottled Sandstone, both in structure and composition, appears to be the most uniform division of the Bunter. In the neighbourhood of Birkenhead, Liverpool, and Ormskirk, the lower portion of this sub-division is red, the upper yellow, and sometimes

[1] It is owing to its poor sandy and gravelly soil that the Forest of Sherwood existed so long, the greater part being still retained as woodland or common. (Aveline.)

sufficiently hard for building purposes. It is developed at Stourport. The town of Birmingham is built principally upon it, and it is exposed near Wolverhampton.

The Bunter beds have not been identified with certainty south of Malvern, but there is a probability of their being represented in West Somerset and Devon (see p. 141). Near Malvern they are represented by 400 feet of red and white sandstones and conglomerate.

The Bunter sandstone yields a good supply of water, being in fact one of the most prolific of the water-bearing strata.

The Bunter Conglomerate of Cannock Chase has, according to Mr. Molyneux, yielded lead and copper ores.

Keuper.

New Red Marl.

The Keuper beds which overlie the Bunter are divided into :—

Upper.—Red and variegated marls with beds of sandstone, 800 to 3,000 feet.

Lower.—Sandstones (Waterstones[1]) having a thickness of 200 feet in Derbyshire and 450 feet in Lancashire.

There is, however, no hard line of demarcation between the two divisions. Keuper is a provincial German term.

Lower Keuper.—This division consists of thinly laminated micaceous sandstones and marls; also of white, brown,

[1] This term was originally used by Mr. Ormerod because the surfaces of some of the beds had a watery appearance, like watered silk. The term as generally understood expresses the water-bearing qualities of the strata.

or reddish sandstone, with sometimes a base of calcareous conglomerate or breccia.

Prof. Hull has given the following general section of their succession :—

> *Waterstones* (passage beds into the Red Marl).—Brownish laminated micaceous sandstones and flags, rippled, with beds of sandy marl.
>
> *Building-stones.*—Fine-grained light-red, brown, yellow, or white freestones, regularly bedded, with occasional beds of red marl, producing the best building-stone of this formation.
>
> *Basement beds.*—Coarse, irregularly-bedded sandstones, calcareous breccia and conglomerate, with bands of marl and mottled calcareous beds similar to the 'Cornstones' of the Old Red Sandstone.

Many foot-prints of Labyrinthodonts (*Cheirotherium*) have been discovered in the Keuper Sandstones, and particularly in Cheshire. Perhaps the quarries at Storeton Hill, on the peninsula of Wirral, are the richest in these traces of ancient life.

The beds have been largely quarried for building purposes at Ombersley and Hadley.

In the neighbourhood of Pattingham and Tattenhall the basement beds have been burnt for lime.

The beds are exposed near Bromsgrove, Kidderminster, and Bridgenorth, near Wolverhampton, Rugeley, Colwich, Eccleshall, Hawkstone Hills, at Overton Scar, and in the Peckforton Hills, Cheshire. They are also seen at Delamere Forest (450 feet), Storeton Hill, in East Warwickshire, at Ashby-de-la-Zouch and Alton in Staffordshire, also in Derbyshire and Nottinghamshire.

Among the local stones may be mentioned the Bank Delf Stone of Bank Quarry near Melling; the Runcorn stone;

the Tinkersdale stone of Grinshill, Shrewsbury; the Durme Stone? of Drayton Basset, Tamworth; and the Kingwood Stone in the neighbourhood of Codsall.

The Lower Keuper sandstones of Alderley Edge have yielded much copper-ore.

Upper Keuper.—The uppermost deposit of the Trias consists very often of Red Marl.

It comprises a series of red and variegated marls, the red colour preponderating, and the beds being mottled with spots and streaks of a grey or green hue.

In the upper part the marl is softer and generally without distinct lines of stratification, and it is usually much broken up and fissured by cracks or joints and miniature faults. The rock presents a rubbly appearance, and is often separated into small masses of a cuboidal or rhombic form. Interstratified with the marl there often occur beds of hard red and sometimes grey or cream-coloured marl, and sandstone.

The presence of carbonate of lime does not appear to be invariable, but the amount is sometimes so trifling as not to be detected by the application of hydrochloric acid.

These red and variegated marls were first identified with the Keuper of Germany by Sedgwick.

Beds of sandstone occasionally occur in the Red Marl. In the neighbourhood of Tewkesbury there is a bed of white sandstone 20 to 30 feet in thickness in the Red Marl.

In the Upper Keuper Sandstones near Taunton, Mr. C. Moore has discovered remains of *Estheria minuta*, fish, *Labyrinthodon*, &c.

Prof. T. R. Jones and Mr. Parker have described a series of Foraminifera from the Red Marl series at Chellaston near Derby.

The Keuper Marl forms fine rich meadow-land; the soil

is well suited for orchards and teazels. It was formerly largely used for marling ground: hence the number of old marl pits.

Alabaster or gypsum (hydrous sulphate of lime) occurs in abundance in some localities in the Red Marl or Gypseous marls of the Isle of Axholme, Newark and Orston, Nottinghamshire; Chellaston and Aston, Derbyshire; near Tutbury, Staffordshire; near Whitehaven, Cumberland; Syston, in Leicestershire; and at Watchet, in Somersetshire.

The purer and variegated kinds are manufactured into ornamental articles, the common sort (but that most largely worked) is converted by burning into Plaster of Paris, which being largely used in forming moulds for the Staffordshire potters, the alabaster is known as Potter's Stone. The very coarse kinds are used as top-dressing for soils.

Celestine, or 'Salt-stone' (Sulphate of Strontian), is found in some abundance in the Red Marl of Gloucestershire and Somersetshire.

Pseudomorphous crystals of rock salt occur abundantly in the Keuper sandstones and marls.

Fullers' earth is raised from the marl beds at Raddle Pits near Braithweel, north-east of Rotherham, also at Renton in Yorkshire; and at Taschbrook, one mile from Warwick, a substance probably of the same nature, as it was intended as a substitute for soap, was raised by the Earl of Warwick.[1]

In Cheshire and Worcestershire beds of Rock-Salt occur, interstratified with the lower beds of the Keuper Marl. In Cheshire, Prof. Hull considers that the Marl has a thickness little short of 3,000 feet. Our culinary salt is largely manufactured from the brine springs. Hence the term 'Saliferous' is sometimes applied to the Upper Keuper strata.

Among the localities are Droitwich and Stoke, in Worcestershire; Northwich, Sandbach, Anderton, Middlewich,

[1] Conybeare and Phillips.

Lawton, Dirtwich, and Nantwich in Cheshire; and Shirleywich in Staffordshire.[1] Prof. Hull states that at Droitwich the salt has been extracted from the brine for upwards of 1,000 years.

The Rock-salt occurs at some places in a massive or granular form, at others in large cubical crystals; Gypsum is often found with it. It is usually of a dull red tint, and associated with red and pale green marls. When lighted up with numerous candles, the vast subterranean halls that have been excavated during the working of Rock-salt, present an appearance which richly repays any trouble that may have been incurred in visiting them.[2]

In Nantwich and other places in Cheshire where the salt is worked, the beds containing it are reached at a depth of from 50 to 150 yards below the surface. The number of saliferous beds in the district is five, and they vary in thickness from six inches to nearly forty feet; a considerable quantity of salt is also mixed with the marls associated with the purer beds.

The descent to the mines is by a shaft, used for the general purposes of drainage, ventilation, &c. The roof, which is about 20 feet above the floor, is supported by pillars about 15 feet in thickness. The Wilton mine, one of the largest, has been worked 330 feet below the surface, and from it, and adjacent mines, upwards of 60,000 tons of Rock-salt were annually obtained; a part of which was exported, and the rest dissolved in water, and afterwards reduced to a crystalline state by evaporating the solution.

The mines, however, are not the only sources from which salt has been obtained, and it is only since the year 1670, when the beds were discovered during an unsuccessful sink-

[1] The houses in which salt is manufactured are called Wych-houses.

[2] For these and the following remarks I am indebted to Prof. Ansted's *Geology* (1844).

ing for coal, that the actual Rock-salt, as a mineral, has been dug out from the mine. Before that time the chief supply was obtained from the brine springs of Droitwich, near Worcester. (Ansted.)

In the Marston mine, near Northwich, there are two thick beds of Rock-salt; the upper 84 to 90 feet, the lower 150 feet in thickness, and they are separated by 30 feet of indurated red clay containing strings of salt.

The Red marl is not a freshwater-bearing stratum. It is necessary to penetrate it before an abundant supply of water is reached; and this is generally met with in underlying sandstones.

Mr. James Plant has given the following general section of the Upper Keuper Beds at Leicester:—

a. Upper Keuper Marls, containing beds of gypsum and several thin bands of green marly sandstone, on which were found numerous pseudomorphous salt-crystals. 80 to 120 feet.

b. Thin sandy shales, with 'way-boards' of green marl. 25 to 30 feet.

c. Thick beds of soft white sandstone (water-stones). 20 to 30 feet.

d. Thin sandy shales, similar to *b.* 35 feet.

e. Red Clay.

The total thickness of the Keuper series near Leicester is from 700 to 1,000 feet. The water-stones are worked for building purposes.

The Red Marls are largely worked for brick-making near Nottingham.[1]

It is needless to indicate the particular geographical distribution of the Triassic rocks, as they can best be seen by

[1] The 'Red Clay of Tuxford' belongs to the series.

reference to a geological map. They form part of the plain of York, and stretch through Nottinghamshire, Leicestershire, Derbyshire, Cheshire, Staffordshire, Warwickshire, Worcestershire, and Gloucestershire, and there is an outlying mass near Carlisle, consisting, according to the Rev. P. B. Brodie, of red marls and water-stones.

TRIASSIC ROCKS OF SOUTH WALES AND THE SOUTH-WEST OF ENGLAND.

In Glamorganshire, Gloucestershire, and in the neighbourhood of the Mendip Hills the Red Rocks consist of Dolomitic Conglomerate, Dolomitic Limestone, Sandstone (generally very calcareous), and Marl.

The Dolomitic Conglomerate, sometimes called 'Millstone' or 'Millgrit rock,' is an old beach deposit of Keuper age, derived chiefly from the Mountain Limestone. It rarely contains pebbles from the Old Red Sandstone, Millstone Grit, or Coal-measure Sandstones, partly because they are not so extensively exposed along the old margins, and partly because most of the sandstones would be of too friable a nature long to resist the friction to which they were subjected.

The included fragments are sometimes well-rounded, but often so slightly worn as to constitute, in fact, a breccia rather than a conglomerate. They vary in size, from that of a pea to boulders two or three feet in diameter; but stones about the size of a hen's egg constitute by far the larger proportion of fragments in the conglomerate. These are cemented together by the Carbonates of Lime and Magnesia, whence the name Dolomitic or Magnesian Conglomerate. Very frequently the cementing material is simply Carbonate of Lime, sometimes it is marl or ferruginous sand; the matrix is usually much coloured by peroxide of iron.

The thickness of the Conglomerate is subject to much variation: it is rarely more than 30 feet.

The Dolomitic Conglomerate is sometimes burnt for lime. It is also used for building and ornamental purposes. The Draycot stone dug near Axbridge is well known in the district.

The Dolomitic Conglomerate usually occurs at the base of the Red Marl, and yet at the same time it occurs at all horizons along the margin of that deposit, where the beds dovetail one into the other, proving that its formation continued throughout the entire series. (See Fig. 8, p. 84.)

Sandstones occur near Brislington, Chew Magna, and Yatton (Claverham or Clarham stone).

At East Harptree beds of chert are associated with the marls and conglomerates.

The remarkably even manner in which the Mountain Limestone has been denuded is well shown at Wallcombe, near Wells, where the Keuper beds rest on the basset edges of this rock. This even line is also very conspicuous in the vales near Frome.

The road to Wookey Hole on the one side of Wells, and that leading to Dulcot on the other, show in places in the Red Marl a bed called the 'Wonder Stone,' described by Messrs. Buckland and Conybeare as 'a beautiful breccia, consisting of yellow transparent crystals of carbonate of lime, disseminated through a dark red earthy dolomite.'

Beds of Dolomitic or Magnesian Limestone are conspicuous near Clevedon, and on the Glamorganshire coast.

Red and brown oxides of iron are not uncommon in the Dolomitic conglomerates, and they have been worked in many places, as at Llantrissant in Glamorganshire, on the Mendip Hills, &c. Reddle has been largely dug near Winford.

In the Dolomitic Conglomerate of Durdham Down, near

Bristol, some Dinosaurian remains have been found, which belong to the genera *Palæosaurus* and *Thecodontosaurus*.

The New Red rocks of West Somersetshire and Devonshire comprise a series of Marls, Sandstones, Conglomerates, and Breccias.

These different lithological divisions are in one sense inconstant, because each modification may occur anywhere in the series; but looked at in a large way, and as indicated in the coast-section between Axmouth and Teignmouth, the following order of succession seems applicable to the country between Porlock, Taunton, and the shores of the English Channel—the classification and thicknesses are taken from a paper by Mr. W. A. E. Ussher:—

	Feet
5. Upper Marls	1,000
4. Upper Sandstones	460
3. Conglomerates or Pebble-beds	80
2. Lower Marls	460
1. Lower Sandstones and Breccias	1,000
	3,000

Thus the Marls (5) sometimes contain beds of Sandstone; the Sandstones (4) contain, in places, beds of Marl, or seams of Conglomerate; the Conglomerates and Pebble-beds (3) contain seams of Sandstone; the Marls (2) sometimes contain sandy sediments, but these are more usually developed at the base; the Breccias and Sandstones (1) dovetail one into the other, more particularly in the higher portion of the division, where they are often capable of being distinguished in mapping, while in the lower portion the breccia is associated with conglomerate: the sandstone often contains beds of breccia, and marly or clayey seams appear in places in the breccia.

In the following section the beds consist of red, brown, and yellow sandstone, with pebbly seams; false-bedding is very conspicuous. They belong to the Upper Sandstone division.

FIG. 13.—*Section of Triassic Rocks near Denbury Farm, Wiveliscombe.*

The Upper Marls appear on the southern edge or escarpment of the Polden Hills, and are visible in several outlying hills in the bordering moors.

From Bridgewater the Marls extend north-west towards Watchet, and southwards through the vale of Taunton, where their boundary with the Upper Sandstone of Halse and Fitzhead is very ill-defined. In an easterly direction the Marl is overlaid by the Greensand of Blackdown, and the extension of the beds is almost concealed east of Kentisbere, where they are not so calcareous as in other places. Near Broadhembury and Kentisbere, alternations of sandstone and mottled clay, which dovetail together, are seen in the lane cuttings. The upper beds, consisting of red and variegated marls, pass upwards into the Rhætic beds at Axmouth. They are well shown at Seaton, Branscombe, and Watchet; and contain Gypsum, particularly at Watchet, and near Somerton.

Pseudomorphous crystals of Rock-salt have been noticed in the lower portions of these beds near Sidmouth.

The underlying Upper Sandstones are generally composed of red rock, often false-bedded and in places mottled with

greenish-grey streaks and patches, and containing hard nodules and ferruginous concretions. Such beds are well shown near Williton, Halse, Ninehead, Wellington, Kentisbere, and Sidmouth. Near Williton the beds are very calcareous, and are burnt for lime.

In the sandstone series of Otterton Point Mr. Whitaker found the jaw of the Lacertilian reptile *Hyperodapedon*; and more recently in the higher portion of the same series of beds, nearer to Sidmouth, Mr. H. J. J. Lavis has discovered several Labyrinthodon remains, which render it probable that others who devote sufficient time to minute examination of these strata may be similarly rewarded.

Beneath the Upper Sandstones come beds of Conglomerate with large pebbles of Grit and Limestone, as at Tipnoller and other quarries east of Wiveliscombe, near Stogumber, Milverton, and Wellington. Sandstone bands frequently occur between the beds of conglomerate. Between the sandstone and conglomerate there is indeed no hard line of demarcation. South of Milverton, and between Halse and Preston Bower, there is a development of pebbly sandstone. (See fig. 13.)

In some localities the limestone pebbles and boulders from the Conglomerate are burnt for lime; and the other pebbles of grit and sandstone are used for road-mending.

The Pebble-beds of Budleigh Salterton are made up largely of flattened quartzite pebbles, containing Palæozoic fossils: these have been traced by Mr. Ussher to the quartzose pebble-beds of Burlescombe.

The term 'Popple-rock' is sometimes applied to the conglomerates, and the Budleigh pebbles are locally known as 'Popples.' There is also the village Newton Poppleford.

The Lower Marls are used for brickmaking near Wiveliscombe and Cullompton.

In Devonshire and West Somerset there are certain beds, included in the New Red Series, which are termed Breccias.

They are made up for the most part of slaty fragments imbedded in a red sandy matrix, and are accompanied, sometimes abundantly, by pebbles of Devonian Limestone, by pebbles of Carboniferous and Devonian grits, and by boulders of Granite and various Igneous rocks.

The Lower Sandstones and Breccias, containing clayey and marly beds, occur at Stogumber, Heavitree, Dawlish, Teignmouth, Kingskerswell, &c. They contain many limestone pebbles, some of which at Teignmouth enclose *Goniatites*, *Clymenia* (*C. linearis*), and many Madrepores. These pebbles are burnt for lime in places.[1]

Some of the brecciated clay beds in the neighbourhood of Exeter and near Torre are worked for brick and tile-making.

The lower beds of Breccia between Teignmouth and Exeter have been long known to contain a variety of felspar called Murchisonite, evidently derived as pebbles from the granitic or igneous rocks (quartz-porphyry, &c.) of the district, yet differing a little in colour and texture from the mineral when found *in situ*. Mr. Ormerod has lately endeavoured to trace out certain horizons in this series by the occurrence of Murchisonite, whence the name 'Murchisonite beds,' which has been applied to these strata.

Although horizontal sections such as that of the coast, and others made up from the numerous quarries and pits, would indicate such a succession as that so well described by my colleague Mr. Ussher, and although all isolated sections agree in indicating a sequence of rocks of tolerably well-defined lithological characters, nevertheless we have as yet no positive proof that the separate divisions that are visible in the coast-section between Teignmouth and Axmouth are continuous one beneath the other, so that at the latter

[1] These pebbles are much sought for on the sea shore, and are derived chiefly from the Breccia, but some perhaps directly from the Devonian Limestone.

locality all would be represented in vertical section were a boring carried through the series.

The indications of a succession of rocks furnished by the coast-section would in most instances be taken as sufficient evidence to warrant the conclusion that in travelling from west to east, newer and newer beds (excepting of course the repetitions occasioned by numerous faults) were exposed. But when the question of the method of accumulation of the strata comes to be solved some difficulties arise.

Thus we have in the country between West Somerset, and Torquay and Axmouth on the South Devon coast, bordering the Devonian and Carboniferous rocks, (1) a margin of breccia and sandstone, (2) one of marl, (3) one of pebble-beds and conglomerate, (4) one of sandstone, (5) one of marl.

It may be observed that nowhere are the conglomerates (3) far removed from the old margin, but the pebble-beds of Budleigh Salterton are seemingly the most distant from their parent rocks. The former are all of local derivation. The derivation of some of the latter is not exactly known; the fossils seem to indicate species of Devonian and Silurian (? Cambrian) age; and although at one time the pebbles were considered to have travelled from the French area, it is now considered that they may have been derived from rocks at no very great distance from the spots where the pebbles are now found; perhaps, as Dr. Hicks has suggested, from rocks destroyed in the formation of the English Channel.[1]

It is at least a significant fact when looked at in a large way that the coarser materials are nearer the old margin, as is the case with the Dolomitic Conglomerate of the Mendip Hills, Gloucestershire and Glamorganshire.

Nor have all the beds been traced persistently across the

[1] The Rev. P. B. Brodie has recorded his discovery, in the Drift of Warwickshire, of pebbles of similar character and with similar fossils to those found at Budleigh Salterton.

country, for one or other of the members is not unfrequently absent, a feature which may be due either to faults or to attenuation. Now it would be impossible for anyone who casually observed the district to offer any opinion on this subject, and I have, I may say almost reluctantly, come to the conclusion, which my colleague Mr. Ussher had before surmised, that the local absence of members is generally due to faults.

The character of the Breccia itself seems to me to be entirely due to the nature of the bordering rocks which formed the old margin of the lacustrine area, and which consisted most largely of slates. Therefore no conclusions as to its age can be drawn from its lithological characters. Sir Roderick Murchison considered it to be Permian, agreeing with Conybeare and Buckland, who identified the Heavitree Breccia with the Roth-liegende of the Germans. It may indeed be difficult to disprove this if we regard the Permian and Trias as one system; and therefore, as the red rocks of Devonshire form a connected series, the use of the term Poikilitic may be preferable to that of simply Trias.

It is indeed a question of great interest as to whether the Red beds of Devonshire be altogether of Triassic age. The lower beds have sometimes been classed as Bunter, while the upper are undoubtedly Keuper, passing gradually upwards into the Rhætic beds east of Axmouth. There is no unconformability in the series, and the thickness would seem to warrant the idea that perhaps the Bunter and also the Muschelkalk may be represented, although without any possibility of their equivalent sediments being identified.

RHÆTIC OR PENARTH BEDS.

The Rhætic beds, so named on the Continent from the Rhætian Alps of Lombardy, where they are well developed, have been identified in England mainly through the researches of Dr. Wright and Mr. Charles Moore. The English and Welsh representatives of the series—the Penarth Beds, so named by Mr. Bristow in 1864—are comparatively feeble in development, but they are not on this account the less interesting and important. They form the connecting link between the Poikilitic and Jurassic strata, a fact of great significance, considering the different physical conditions under which these two great groups of strata were deposited. The Rhætic beds bind them together as one great conformable sequence of deposit. Much discussion has arisen as to whether these passage-beds are more closely allied to the Trias or to the Lias; there is no doubt, however, that they belong as much to the one formation as to the other. The Palæontological evidence, afforded by the fish-remains which occur in the middle shaly division, would, as was pointed out by Sir Philip Egerton many years ago, incline us to connect the Bone-bed with the Trias; whereas the fossils of the upper strata, and the mollusca generally, would link the Rhætic beds with the Lower Lias, from which, nevertheless, they are distinguished in this country by the entire absence of Cephalopoda. As a matter of convenience, and to avoid giving too great a prominence to the strata, it seems best to include them with the Trias, as the uppermost formation in the Poikilitic system.

The Rhætic Beds consist of a series of marls, black shales and white limestones, having an average thickness of about 50 feet. The series admits of the three following subdivisions:—

		Feet
White Lias,	about	12
Black Shales	"	12
Grey Marls	"	24

The White Lias comprises many beds of white limestone, capped by a hard smooth-grained stone called the Sun bed, which from its closeness of texture and general purity has been recommended for purposes of lithography. At or near the base of the White Lias is found the Cotham or Landscape Marble, so well known from the dendritic markings which occur throughout it.[1] It is found in impersistent masses from two or three to eight inches in thickness, and is present generally where the White Lias is developed in the southern part of Gloucestershire, in Somersetshire, even to the coast-section near Lyme Regis in Dorsetshire.

The black-shales or paper-shales form perhaps the most characteristic and persistent portion of the Rhætic series. They are much impregnated with iron pyrites, and contain the well-known bone-bed,[2] of which sometimes there are one or two bands: these consist of pyritic and micaceous sandstone containing the bones, teeth, palates and coprolites of fish.

The Grey Marls at the base of the Rhætic series graduate so imperceptibly into the Red Marls of the Trias, that sometimes they are included in that formation. The mere difference in colour between the deposits is subject to so much variation that although the red disappears in the Rhætic marls, yet the boundary-line drawn solely in reference to colour can never be taken as a true physical horizon.

The Rhætic beds, where they approach the old Palæozoic land of the Bristol Coal Basin, the Mendip Hills or South

[1] It is considered that these markings are produced by infiltration of ores of manganese and iron.

[2] Formerly called the Lias Bone-bed.

Wales, frequently overlap the New Red rocks, whether Red Marl or Dolomitic Conglomerate, and repose directly upon the older rocks. They then sometimes present conglomeratic characters. (See Fig. 8, p. 84.)

The Rhætic beds, wherever sections have been obtained, have been found to be present between the Red Marls and Lower Lias. They may therefore be said to extend across England from near Redcar on the coast of Yorkshire to near Lyme Regis on the coast of Dorsetshire.

They occur in Cumberland near Carlisle, in Staffordshire (Needwood Forest), Shropshire, Warwickshire, Leicestershire, and in Glamorganshire, South Wales.

In Yorkshire 10 to 20 feet of blue or grey limestone, generally laminated and shelly, with partings of whitish clay or marl, rests immediately upon the red gypseous marls of the Keuper.

The White Lias seems to be feebly represented in Lincolnshire, Nottinghamshire, and Leicestershire, and there appears to be a development of greyish marly beds in part replacing the White Lias, which becomes so conspicuous in Somersetshire and Dorsetshire. At Penarth the White Lias is scarcely traceable.

The Rhætic beds are well exposed near Watchet, where the thickness is 150 feet, which is only equalled elsewhere in England at Queen Camel near Yeovil.

Amongst other sections are those of Garden Cliff, Westbury-on-Severn (Westbury Beds), Aust Cliff, Saltford, Uphill cutting, Puriton and Shepton Mallet.

The Wedmore stone is a shelly limestone locally met with in the Rhætic beds near Wedmore; and the 'Flinty bed' is a compact limestone with alternating shelly layers, found near Beer Crocombe, in which Mr. Moore has obtained many species of mollusca.

The fossils of the White Lias are *Ostrea Liassica*, *Mo-*

diola minima, *Cardium Rhœticum*, *Monotis decussata*, Annelid-tubes, &c.

In the Black-shales and intercalated bone-beds and thin sandy seams are *Avicula contorta*;[1] *Pecten Valoniensis*, &c.

Fig. 14.—*Section of Lower Lias and White Lias, near Bath.*

(Midland Railway, near Weston Station, looking east.)

Lower Lias.
White Lias (Rhætic).

Valley Gravel.
Lower Lias.

Sandy beds are sometimes found, crowded with casts of *Pullastra arenicola*.

The grey marls have yielded but one fossil, but that is of the highest interest, being the tooth of the oldest known British Mammal, *Microlestes* (*Hypsiprimnopsis*) *Rhœticus*, which was found by Mr. Boyd Dawkins at Watchet.

Edward Forbes (nearly 30 years ago) expressed his opinion that the fauna of the White Lias was curiously representative of the existing Caspian fauna. He then broached the notion that the Red Marls were formed in a great salt inland sea (a sort of Aralo-Caspian), during the last state of which the White Lias was formed; that the bed was then (if not

[1] Hence the beds have been termed the zone of *Avicula contorta.*

elevated) depressed and turned into a part of the ocean, when the Liassic fauna came in.[1]

At a meeting of the British Association held at Bath in 1864, Mr. Moore described three cartloads of deposit containing Rhætic fossils which he had found washed into a fissure of Mountain Limestone near Frome. From this he had obtained twenty-nine teeth of the oldest Mammals (*Microlestes Moorei*), three only having been previously found, together with relics of nine genera of Reptiles, most of them new to this country, and fifteen genera of Fishes. Mr. Moore also produced 70,000 teeth of the *Lophodus* alone as the result of his labour, and stated that the three loads of clay had yielded him probably one million specimens.

The White Lias beds are used for building purposes, and are burnt for lime. The grey marls have been used for marling land.

The Rhætic beds generally form a gentle escarpment overlooking the vales of New Red Marl, and the junction with the beds below is frequently conspicuous in the ploughed fields. Springs are given out at the base of the White Lias.

[1] Memoir of Edward Forbes, 1861, p. 418; see also Ramsay, *Quart. Journ. Geol. Soc.*, vol. xxvii. p. 189.

SUB-SECTION JURASSIC.

CHAPTER VI.

LIASSIC.

THE Jurassic system includes the several members of both Lias and Oolites, and derives its name from the development of these strata in the Jura mountains between France and Switzerland.

The Liassic and Oolitic rocks have been conveniently grouped into different stages or sections, which are characterized by certain marked lithological features, and by certain assemblages of organic remains. Although these characters are remarkably persistent over large areas, yet the different stages display a considerable variation in thickness when traced across the country, and some of them are quite locally developed.

When we proceed to correlate the Liassic and Oolitic rocks of the south-west of England with the same beds in the midland and north-eastern counties, we find that many difficulties present themselves. The variations in thickness, in the lithological subdivisions, and in the assemblages or zones of organic remains, are striking. When, however, we look to the physical history of the period, and the method of deposition of the sediments, such changes appear but natural. We cannot for one moment suppose that an argillaceous, a sandy, or a calcareous deposit was formed

continuously and contemporaneously over the entire country, although any one of these deposits might be laid down over a considerable area. Such deposits were in some instances, no doubt, all being formed at the same time. The great variations in thickness and other modifications exhibited by the Liassic and Oolitic series seem to indicate that their subdivisions were not formed contemporaneously, but that a clayey condition, such as that which produced the Upper Lias, prevailed longer in one tract than in others, and the same thing may be said of the Midford Sands. The great thickness of Fullers' Earth would likewise indicate a period of time which, in tracts where it has thinned away, was occupied by the deposition of rocks of a different lithological nature.

Thus the conditions of sedimentary deposit may have changed at different times in different areas, and these changes would be marked as a rule by the modifications in the assemblage of organic remains which were suited to the then prevailing physical conditions.

The clayey beds, it should be observed, are more persistent than the sandy or calcareous strata.

Prof. Ramsay considers that the Liassic and Oolitic formations were sediments laid down in warm seas surrounding an archipelago of which Dartmoor, Wales, and Cumberland formed some of the islands.

The finer sediments were, no doubt, brought down by rivers; the calcareous sands and freestones have been formed from comminuted shell and coral; while evidences of coral-reefs occur at some horizons.

The rapid alternation of limestone and clay in the Lower Lias is remarkable, but may perhaps be partly accounted for by segregation, the hard beds often having a nodular appearance, and frequently occurring in isolated nodular masses.

The condition of an embayed sea near a large continent, such as is now seen on the eastern shores of Asia, where

rivers, running over extensive flats, pour their waters into a sheltered portion of the ocean, is, in Prof. Ansted's opinion, likely to have attended the deposition of the Liassic strata.

LIAS.

The term 'Lias' is supposed to be the corruption of a word indicating *layers*, for the Lias is characterized, on the whole, by marked regularity in the strata which compose it. These for the most part comprise alternations of argillaceous limestone and clay or shale.

The Lias forms a conspicuous band stretching across England from Whitby and Redcar, on the coast of Yorkshire, to Lyme Regis on the coast of Dorset; the harder rocks forming gentle escarpments which overlook the vales formed in the softer or clayey strata.

The organic remains of the Lias are rich and varied: the numerous forms of Ammonites and Belemnites, and many other marine Mollusca, are very characteristic, and indicate its essentially marine formation, although here and there evidences of estuarine conditions are met with. The remains of Reptiles, particularly of the genera *Ichthyosaurus* and *Plesiosaurus*, have led some to designate the period as the Age of Reptiles, or Saurozoic Epoch.

Lower Lias.

The Lower Lias consists in its lower portion of blue and brown argillaceous limestones, with partings of clay or shale, often bituminous; in the higher portion the clay preponderates, and there are only occasional bands of impure limestone, generally nodular.

The thickness of the Lower Lias is subject to much variation, and more particularly in the west of England and South Wales, where some conglomeratic modifications are met with.

The study of the fossil contents of the Lias has led palæontologists to make certain subdivisions based upon the apparent succession of life. The most important of these are the Ammonite-zones of Dr. Wright, who, following Dr. Oppel, divided the Lower Lias as follows:—

6. Zone of *Ammonites*	*raricostatus*	Dark-coloured clays.
5. " " "	*oxynotus*	Blue clays with iron pyrites.
4. " " "	*obtusus*	Clay and marl with inconstant bands of limestone.
3. " " "	*Turneri*	Light-coloured argillaceous and shelly limestone and slaty clay.
2. " " "	*Bucklandi*[1] (vel *bisulcatus*)	Bluish argillaceous limestone and clay.
1. " " "	*planorbis*	Hard grey limestones.

The 'Saurian and Ostrea beds' are frequently recognized as zones at the base of the Lower Lias.

The value of these divisions has frequently been questioned, as, owing to the absence of Ammonites, the zones are very often indeterminable. The meaning of the term *zone* is well expressed by Mr. Ralph Tate in the following paragraph. 'The Lias can conveniently be subdivided into zones or stages, characterized by organic remains, and generally by lithological features, the former being more or less a consequence of the conditions which produced the latter; and thus the zones mark different conditions of sea bottom and of life. Species of *Ammonites*, being the most restricted in range of the common fossils of the Lias, and moreover easily identified, have been selected as *indices to the zones*; but their presence alone does not warrant us in assigning this

[1] Some palæontologists recognize another zone between those of *A. Bucklandi* and *A. planorbis*, namely, the zone of *A. angulatus*.

limestone to the zone of *Ammonites angulatus*, or that clay to that of *Ammonites Turneri*, as the case may be; for they may range through several zones. And the Ammonite which gives its name to a zone is but one of many which mark a determinate stage in the life-history of the formation. Hence the zone is a zoological one, and signifies an assemblage of species, and not the range of an *Ammonite*.' (See p. 157.)

Near the base of the Lower Lias in Gloucestershire there is a bed of limestone about a foot in thickness, termed the Insect limestone, in which the Rev. P. B. Brodie has obtained many Insect remains.

In Somersetshire other palæontological zones have been identified by Mr. Moore, as the Spirifer-bank which at Camerton and Radstock yields such fine specimens of *Spirifer Walcotti*, and the Foraminifera zone; both of which underlie the zone of *Ammonites raricostatus*.

The Lias has always been a favourite collecting-ground for those in search of fossils. It is a formation easily recognized, and its fossils, when found, can generally be extracted without much difficulty.

Whitby has long been famous for its snake-stones (Ammonites), but so great has been the demand for these, that I am informed supplies have been sent there from other localities—a fact which collectors should bear in mind, as few fossils are of any scientific value unless the locality they come from be definitely known.

In addition to the fossils before mentioned, the following species may be given as characteristic of the Lower Lias:—Mollusca: *Ammonites Conybeari*, *Nautilus striatus*, *Belemnites acutus*, *Gryphæa incurva* (*arcuata*) (Devil's toe-nail), *Unicardium cardioides*, *Cardinia Listeri*, *Pholadomya glabra*, *Lima gigantea*, *Avicula cygnipes*, *Hippopodium ponderosum*, *Pleurotomaria Anglica*, and *Rhynchonella variabilis*; Crinoids: *Extracrinus briareus*, *Pentacrinus*;

and the Coral *Isastrea Murchisoni.* Crustacea of the genera *Eryon*, *Glyphea*, and *Scapheus* are sometimes met with.

Among the fish may be mentioned *Lepidotus*, *Acrodus*, &c. The Ichthyodorulites are the large bony spines of fish, as *Hybodus*, allied to the *Cestracion* and *Chimæra*.

The reptiles include species of *Ichthyosaurus* and *Plesiosaurus*; of the former, specimens 24 feet in length have been obtained; and of the latter, with its long neck, specimens have measured from 18 to 20 feet.

In the upper clayey beds of the Lower Lias the fossils are often pyritic.

Among the many places of geological interest in England, none has, perhaps, attracted more visitors, and particularly foreigners, than Lyme Regis.

Well situated as it is for the study of stratigraphical and physical geology, its fame is due, perhaps, more to the richness of its Liassic fauna than to the beauties and wondrous effects of its landslips. The numerous remains of fish and giant reptiles, not to mention the many and varied forms of invertebrate life, have attracted many an eager collector. It is true that the Lias in its three members of Upper, Middle, and Lower, has yielded an abundance of organic remains; and yet many who visit the cliffs of Lyme in search of specimens return disappointed. One may walk from Seaton to Charmouth, and, perhaps, hardly find a specimen worth carrying away, or should one be found, its size, or the toil of extracting it, may overcome the patience of the investigator. The fact is, the fossils occur at particular horizons, and it is only by much time and labour that good specimens can be obtained. It is not that Lyme Regis was a remarkably favoured locality for the entombing of organic remains—the large exposures of lias, and the number of collectors, have made it famous. At Street, near Glastonbury, there are

very large quarries in the Lias, and here numerous fish and reptilian remains have been found in an abundance almost equal to that at Lyme Regis. But most of the specimens that enrich our public museums and large private collections have not been obtained by a single visit, but have been gathered by the quarrymen or those professionally engaged in collecting during the labours of many years.

The thickness of the Lower Lias of Dorset has been estimated at 700 feet. In Somersetshire the thickness varies from a few feet to 300 feet.

In the neighbourhood of Wedmore, at Street, and along the Polden Hills, the lower beds are considerably modified. Here we have comparatively soft argillaceous limestones, sometimes graduating into a marl, together with coarse and compact blue limestones (called 'clog'). The clay-bands are in great part represented by slaty marls.

Peculiar cherty modifications of the Lias occur on the Mendip Hills at Harptree Hill, near Chewton Mendip and East Harptree.

Local modifications of the Lower Lias also occur near Shepton Mallet, where the deposit presents shore-conditions and consists of sandy limestone and conglomerate, without the usual clayey partings. In the Radstock Coal-district, moreover, the deposit exhibits a remarkable attenuation from suspension of sediment. (See Fig. 8, p. 84.)

The Lower Lias in the Vale of Ilchester consists of three members:—

1. Blue and brown clay (worked for brick-making).
2. Even bedded blue limestones and shales (the limestones are largely quarried).
3. Rubbly white earthy limestones and marls, with *Ostrea Liassica* and *Modiola minima*.

The first and uppermost division occurs over the flat country bordering the Marlstone escarpment.

In Glamorganshire the Lower Lias or Lias Conglomerate frequently exhibits shore-conditions. The beds are well exhibited in the cliffs at Sutton, Southerndown, and Dunraven. Sometimes the beds approach in character the Carboniferous Limestone, so that it is difficult to distinguish between them. The Conglomerates are formed of Carboniferous Limestone pebbles.

Mr. Bristow has stated that on the shore, where the sections are exposed to the influence of sea-water, they have become silicified, and so hard that it is exceedingly difficult to hammer the fossils out of the rock; while the calcareous shells of the fossils themselves, between high and low water mark, have sometimes been replaced by chalcedony.

At Sutton, the stone is described by him as a white tufaceous freestone. The clayey beds seem entirely to have disappeared.

The Lower Lias is largely developed in Gloucestershire, Worcestershire, and Warwickshire.

In Warwickshire the thickness is upwards of 600 feet. Outliers of Lias, with intervening Rhætic beds, occur at Copt Heath (Knowle), and Wootton Wawen in South Warwickshire. The lower beds are well shown at Wilmcote and Binton, near Stratford-on-Avon, where they have been largely quarried.

In Leicestershire the Lower Lias attains a thickness of 520 feet; the upper portion consisting chiefly of clays, and the lower 20 feet of limestones.

According to Mr. Judd, the cuttings on the Syston and Peterborough Railway, between Kirby and Whissendine, exhibit the best illustration of the Lower Lias beds in that district. The following are the general divisions which he has made:—

i. Blue clays with much pyrites and many septaria; *Ammonites capricornus, Pentacrinus.*

h. Shelly limestones with *Cardinia, Hippopodium ponderosum.*

g. Blue laminated pyritous shales, with thin bands of limestone, *Ammonites bipunctatus, Spirifer Walcotti, Pentacrinus, &c.*

f. Sandy clays.

e. Clay with much pyrites (producing selenite by its decomposition), *Belemnites clavatus, Plicatula spinosa.*

d. Ferruginous limestone, *Ammonites semicostatus, Cardinia, Gryphæa incurva.*

c. Clay with bands of pyrites, *Ammonites angulatus.*

b. Coarse grained and shelly limestones, *Ammonites planorbis, Nautilus, Lima gigantea.*

a. 'Fish and Insect Limestones,'[1] finely laminated argillaceous limestone alternating with shale, and abounding with remains of fish, crustaceans, saurians, plants, and sometimes insects. Extensively worked at Granby, Barrow-on-Soar, &c., for the manufacture of hydraulic cement.

In Northamptonshire the Lower Lias has a thickness of about 650 feet.

In the north-west of Lincolnshire, as pointed out by the Rev. J. E. Cross, there is a valuable bed of ironstone, covering the wide plain on which is situated the village of Scunthorpe, which has lately been worked. It occurs low down in the Lower Lias, and is possibly on the same horizon as a bed of ironstone worked at Caythorpe, near Grantham.

In Yorkshire the following divisions are given by Prof. Phillips:—

3. Clay or shale, 300 to 500 feet, containing many earthy limestone-nodules, and not many fossils; *Pentacrinites, Gryphæa MacCullochii, &c.*
2. Gryphite limestone, 12 to 20 feet, occurring in rough shelly beds; *Gryphæa incurva* very abundant.
1. Clay with septarian nodules, *Ammonites, Lima, Pentacrinites.*

In Cumberland, near Carlisle, there is about 120 feet of dark shales and limestone (including Rhætic beds), in which the Rev. P. B. Brodie identifies the Lima and Saurian Beds.

[1] Mr. Judd suggests that these beds be called the 'Strensham series.'

Economic Products, &c., of Lower Lias.

The Lower Lias limestones are much quarried for building and paving purposes, and to be burnt for lime.

The quarries of Street and Keinton Mandefield, in Somersetshire, yield very large slabs, not uncommonly 12 feet square. The Thurlbeer Lias and Knapp Stone are locally known near Taunton.

The cement-stones at the base of the Lias at Barrow-on-Soar have been largely worked for the manufacture of hydraulic cement. The Limestone Beds at Lyme Regis and Aberthaw are similarly noted.

The 'Ammonite Marble' found at Marston near Yeovil is composed of *A. planicosta.*

The Lower Lias Clays are often used for brick and tile-making. Some of them are very bituminous, and near Chard and Axminster they have, early in the present century, led to fruitless trials for coal. Similar trials have been made at times in Lincolnshire and Leicestershire.

The soil is brashy and often of a rich brown colour. Corn, oats, mangel-wurzel, turnips, cabbages, and, in places, beans and teazels are cultivated.

The ground is generally flat or gently undulating, forming vales, with an escarpment at the junction with the Rhætic beds, overlooking the vales of Red Marl.

The Lower Lias is not a water-bearing stratum, but holds up or throws out water when porous beds rest above it.

The pasture-lands on the clays furnish material in the vale of Gloucester for the celebrated 'double Gloucester' cheese, and near Melton Mowbray and Leicester for the 'Stilton.' Cheddar cheese may be said to be the product of the pasturages on the Liassic Clays, Red Marl and Alluvium of Somersetshire.

Middle Lias.

The Middle Lias, or Marlstone as it was called by William Smith, consists generally of two members. The upper 'Brown rock' or 'Rock bed' (=Marlstone proper) comprises tough iron-shot argillaceous limestones or marlstones; the lower member includes micaceous sands and clays, and occasional nodular limestones.

The Middle Lias varies in thickness from one or two feet to over three hundred feet.

It has been divided Palæontologically into five zones, as follows:—

5. Zone of *Ammonites spinatus.*
4. " " " *margaritatus.*
3. " " " *capricornus.*
2. " " " *ibex* or *Henleyi.*
1. " " " *Jamesoni.*

Ammonites spinatus and *A. margaritatus* characterize the Rock-bed; and the other species the lower micaceous sands and clays.

These zones, although determined in the Cotteswold Hills by Dr. Wright, have not been made out further south, partly because the Middle Lias becomes very much attenuated and modified, and also because the lower beds are rarely exposed. At Ilminster, Mr. Moore observes that *A. margaritatus* and *A. spinatus* occur together, that *A. Bechei* passes upwards from the lower beds into the marlstone, and *A. fimbriatus*, *A. variabilis*, and *A. radians* are common to the Middle and Upper Lias, so that we cannot rely upon the precise range of these cephalopoda in our determination of geological horizons, which can be proved to apply equally to others from the lower beds. (See p. 150.)

The Lower Lias passes upwards into the Middle Lias by insensible gradation. The boundary-line between the two formations is essentially a palæontological one, and therefore

lithologically there is no hard or marked division. It is indeed one of the most vague boundary lines that is drawn upon geological maps.

The lower beds of the Middle Lias consist of a series of blue clays, often very calcareous, and with intercalated beds of nodular limestone; higher up the beds become micaceous, then very sandy, and the highest beds consist of clay.

The fossils are decidedly most numerous in the Marlstone. This bed at Ilminster has yielded 183 species to the industry of Mr. Moore. These include Plant-remains, Foraminifera, Echinodermata, Crustacea, Brachiopoda, Conchifera, Gasteropoda, Cephalopoda, bones of *Ichthyosaurus*, teeth of *Hybodus*, and scales of *Lepidotus*.

Amongst the characteristic fossils not before mentioned are:—*Ammonites armatus*, *Belemnites elongatus*, *Hinnites abjectus*, *Pecten æquivalvis*, *Myacites unionides*, *Pholadomya ambigua*, *Modiola scalprum*, *Gryphæa gigantea*, *Rhynchonella tetrahedra*, &c.

Near Lyme Regis Mr. Day has observed a feeble representation of the Marlstone, but this rock, so conspicuous and so fossiliferous in the neighbourhood of Ilminster, has generally died out in the district to the south. The divisions of the Middle Lias, whether sandy or clayey, are subject to much variation, but in the Dorsetshire sections sandy deposits seem to characterize the upper portion of the series. At Golden Cap, according to Mr. Day's estimates, the Middle Lias is about 350 feet in thickness. The Starfish-bed is a seam containing *Ophioderma Egertoni*.

In Somersetshire the Middle Lias is tolerably persistent in the escarpment below the Oolites. It is found at Glastonbury, Pennard, and Brent Knoll; it is very thin in the Radstock country,[1] and generally very obscure near Bath.

[1] The Middle Lias is so thin in this district that it was found impossible to separate it from the Lower Lias, on the Geological Survey Map.

In the Cotteswold Hills the Middle Lias has a thickness of about 120 feet, the Rock-bed being 12 to 20 feet; at Bredon Hill the total thickness is 310 feet; at Wotton Underedge the Rock-bed is 12 feet, and the lower strata 186 feet. (See Fig. 15.)

In Warwickshire the Middle Lias is represented by little else than the Marlstone.

In Oxfordshire the lower beds, about 10 to 20 feet in thickness, consist of sands, clays, and sandstones; and the rock-bed, with much iron-ore, is about 10 or 12 feet in thickness.[1] Mr. T. Beesley observes (1873) that for a long time past attempts have been made to introduce the Marlstone of this district as an available ore of iron; but it is only within the last three years that these attempts have met with success. Extensive excavations are now being carried on at Adderbury and King's Sutton, near Banbury.

In Northamptonshire the Middle Lias is about 30 feet in thickness.

In Rutlandshire and Leicestershire the Marlstone or Rock-bed varies much in thickness, attaining about 18 feet at Tilton-on-the-Hill, and diminishing to 8 or 9 feet near Oakham. Mr. Judd mentions that in this area it is not dug as an ironstone, as it was in former times. It is, however, quarried for building purposes, and in some places burnt for lime. The soil on this rock is of a red colour, and highly productive.[2]

In N. W. Lincolnshire the Marlstone is but 8 feet in thickness.

In Yorkshire and Lincolnshire the Middle Lias series is from 100 to 150 feet in thickness. Prof. Phillips remarks that in this tract the Marlstone is allied zoologically rather

[1] The Blenheim iron-ore occurs in this formation.

[2] Mr. Judd observes that the county of Rutland (red land) probably acquired its name from the prevalent colour of the soil.

to the Oolites than to the Lias proper. The beds consist of clays and ironstone-bands with irregular partings of shale and sandstone, and contain *Terebratula, Rhynchonella, Pecten, Cardium, Avicula*, &c.

The Cleveland Iron-ore is well known; it is derived from the Middle Lias of the Cleveland Hills in Yorkshire. The ore occurs in several seams, but the main bed of ironstone is from 15 to 20 feet in thickness. The beds worked extend inland from near Redcar to Eston, near Middlesborough-on-Tees.[1] The ore is an impure carbonate, and it is highly fossiliferous.

In regard to the economic uses of the Middle Lias, the Rock-bed is quarried for rough building purposes and for road-metal. It is sometimes burnt for lime. The lower beds are worked in places for brick-making.

The Middle Lias furnishes a rich soil, particularly favourable in Somersetshire to the growth of apple trees.

At Northampton the beds yield a copious supply of water to the town.

Upper Lias.

The Upper Lias is essentially a clay-formation, consisting of bluish shaly clay, with nodules of blue limestone.

It is characterized by the presence of *Ammonites serpentinus, A. bifrons, A. annulatus, A. communis*,[2] *Nautilus intermedius, Belemnites compressus, B. elongatus, Leda (Nucula) ovum*, &c.

[1] Cleveland is, strictly speaking, but a small portion of the North Riding of Yorkshire, probably about one-third of it; but from the fact that the staple industry is the same throughout a large part of Teesdale and South Durham as in Cleveland proper, the term has now popularly acquired a more extended signification. *Quart. Journ. Science*, April, 1870.

[2] It is sometimes termed the zone of *A. communis*.

Sometimes the following zones may be determined:—

4. 'Leda ovum Beds.'
3. 'Communis Beds.'
2. 'Serpentinus Beds.'
1. Paper-Shales with Fish and Insect Limestones.[1]

The Upper Lias in Dorsetshire is represented by a clay-deposit, estimated by Mr. Day to be 70 feet in thickness.

Spontaneous combustion, due to decomposition of iron-pyrites, or Marcasite, has sometimes taken place in the cliffs near Charmouth.

The Upper Lias has a very meagre development in Somersetshire, but at the same time it presents many features of great palæontological interest, which have been made known by Mr. Moore. Its thickness is seldom more than 8 or 10 feet, and it consists of thin beds of blue clay, rubbly and nodular limestones, which are sometimes septarian. The most remarkable bed is the Saurian and Fish-bed, consisting of nodular yellow limestone, which has yielded beautiful remains of *Ichthyosaurus*, *Teleosaurus*, numerous fish, Cephalopoda,[2] Insects, and Crustacea. This bed occurs near Ilminster.

It is remarkable how the shape of the nodule conforms roughly to that of the enclosed organism, and Mr. Moore points out that, when a specimen is enclosed of greater size or length than usual, the nodule is invariably septarian.

Beneath the Saurian and Fish zone come the Leptæna beds, characterized by the presence of *L. Bouchardii* and *L. Moorei.*

[1] Mr. Judd has suggested that these beds be called the 'Dumbleton Series,' from the locality at which they were first studied by the Rev. P. B. Brodie.

[2] These include the genera *Geoteuthis* and *Teudopsis*. The softer parts of these cuttle fishes have perished, leaving only the internal cuttle-bone, in the centre of which the ink-bag is usually found, still charged with its black pigment.—(Moore.)

According to Mr. Moore the beds present evidence of slow deposition, and, in places, of estuarine conditions.

The beds are well seen at Glastonbury Tor and Brent Knoll, and they have been detected here and there in the Oolitic escarpments between Yeovil and Bath. They also occur at Dundry Hill.

In Gloucestershire the Upper Lias varies from about 10 feet at Wotton Underedge to about 300 feet at Cleeve Cloud, and 380 feet at Bredon. In Oxfordshire it is sometimes very thin, only a few feet: in places it is 40 feet. In Leicestershire the thickness is about 300 feet; in Northamptonshire ('Blue Marl') it varies from 150 to 200 feet; and in Lincolnshire the thickness diminishes to about 60 feet.

The Upper Lias or Alum shale of Yorkshire (according to Prof. Phillips) consists of a blue shaly deposit containing numerous nodular layers of earthy limestone, or nodules frequently containing Ammonites and other organic remains. Its thickness varies from 200 feet on the coast to 50 feet and less in some of the southern Cleveland Hills.

A considerable quantity of jet is found in the lower beds, specimens of which may often be picked up on the shore at Whitby. This is one of the most valuable products of the Yorkshire coast, being extensively worked into ornaments. Prof. Phillips observes that it is simply coniferous wood, and in thin sections it clearly shows the characteristic structure. Impressions of Ammonites and other fossils sometimes appear on its surface.

Alum occasionally appears as an efflorescence on the surface-rocks, which are then designated as alum-shale. These rocks usually contain only the constituent parts of alum, and not the mineral itself. The shaly beds have, however, been found extremely convenient for the manufacture of alum The cliffs near Whitby, from three to four hundred feet in height, are composed of very dark grey beds of shaly clay,

lying nearly horizontal, and stretching out at the base into an extensive flat pavement, on which the sea washes, and which is laid bare to a considerable distance at low water. Mingled with this clay is a large quantity of iron pyrites, which is sometimes so abundant that spontaneous combustion takes place when the beds are exposed to atmospheric action. The clay itself is of a silky lustre, and splits very readily into thin laminæ, but is sometimes extremely hard when dry. The shale is roasted until the sulphur of the pyrites combines with the alumina and potash, and forms a soluble salt (Alum), which is manufactured at Whitby and Redcar.[1]

The Upper Lias clay is frequently used for making bricks, tiles and drain pipes.

[1] These remarks are taken from Prof. Ansted's *Geology*.

CHAPTER VII.

OOLITIC.

THIS term indicates the characteristic features of many of the limestones in the group, which have an oolitic structure. Oolite or roe-stone (derived from the Greek *oon*, an egg, and *lithos*, stone) is a name applied to limestones composed of small round particles of calcareous matter, which are cemented together and resemble the roe of a fish. When these particles approach the size of a pea the rock is termed Pisolite, Pisolitic limestone, or Pea-stone.

Thus we have the Inferior Oolite, the Great or Bath Oolite, the Oxford Oolite, and the Portland Oolite; also the Pea-grit, a local member of the Inferior Oolite.

According to Prof. Phillips, the formation of oolitic grains seems to have followed on the accumulation of calcareous mud; in some cases the whole of this mud has become oolitic, in others segregations of distant sphericles took place. In general the small masses appear to have been gathered by attraction out of calcareous mud around nuclei of previously solidified matter—minute fragments of coral, echinida, foraminifera, and various shells—and, in some cases, grains of sand. But in other cases the oolitic structure seems to be independent of any internal nucleus, and must have been produced by chemical and molecular changes in the rocks.

The oolites, although characteristic of the series, by no means constitute its bulk: they are interstratified with sands and clays, and seemingly in places in so regular a sequence of sand, clay, and limestone, that much remark has been

made upon the subject. But this ternary or tripartite series is after all very local; the divisions that are made in the south of England do not correspond lithologically with those made in the north of Oxfordshire and the southern part of Northamptonshire, nor with those made in the northern part of Northamptonshire and Lincolnshire; whilst a comparison between the 'Yorkshire Oolites' and those of the Cotteswold Hills shows more strikingly the changes undergone by the strata, for in Yorkshire the beds are essentially arenaceous.

Prof. Hull has put forward reasons for concluding that all the Lower Jurassic formations exposed in the western and central counties die out towards the south-east; that this attenuation is due to the increase of distance from the sources of supply, and the consequent failure of sedimentary materials which were derived from land occupying the region of the North Atlantic. Such attenuation may in some cases, as pointed out by Mr. Topley and Mr. Lucy, modify our estimates of the dip.

As before observed, the persistence of the different types of strata varies much; the development of the oolites and sandy strata being more restricted than that of the clays. And it happens also in places that where one calcareous division is well developed, another in the same district becomes attenuated, as is the case with some of the Silurian limestones. Thus near Bath, where the Great Oolite is so well displayed, the Inferior Oolite is not so conspicuous; while the latter gains importance in its southward extension into Dorsetshire, where the Great Oolite has died out. Again the Lincolnshire limestone (Inferior Oolite) is more largely and prominently developed where the Great Oolite has a comparatively feeble representation. The Kelloway Rock and the Cornbrash may be cited as being amongst the most persistent of the calcareous strata.

The Oolitic strata appear to rest quite conformably upon

the Liassic sediments, but the whole Jurassic series exhibits many and great variations, and the lower beds of the Oolitic series sometimes appear to rest directly upon strata containing remains of Lower Lias, as types in Somersetshire.

It is indeed questionable whether there is any evidence of great unconformability in the Oolitic series in England, and whether the absence of individual members in certain places may not be due to local changes of condition, and in some cases perhaps to paucity of sediment: to conditions, in fact, which would affect the character both of the sediment and of the organic remains. Pauses in deposition are indicated at all horizons in some of the limestones; but there are no positive evidences over any extensive area, of the removal of any absent division, by denudation in Oolitic times.

Most of the strata are truly marine, but there are in places evidences of estuarine conditions; and Prof. Phillips considers that in Yorkshire the strata give evidence of a true coal-field in the Oolitic era, produced by the interposition of vast quantities of sedimentary deposits brought down by floods from the land, between the more exclusively marine strata of the ordinary Oolitic type.

LOWER OOLITIC.

The following divisions have been established by the Geological Survey so far as the Midland and South-Western Counties of England are concerned: those in Yorkshire are given on the authority of Prof. Phillips, Dr. Wright, and Mr. Hudleston.[1] The different beds cannot be correlated with precision; the numbers refer to those which may roughly be considered as homotaxeous.

[1] It is only right to state that this Classification was primarily based on the labours of William Smith, followed by Lonsdale.

Table showing the Subdivisions of the Lower Oolitic Rocks.

South-West of England [1]	N. Oxfordshire and S. Northamptonshire [2]	N. Northamptonshire and S. Lincolnshire [2]	Yorkshire.
6. Cornbrash.	6. Cornbrash.	6. Cornbrash.	6. Cornbrash.
5. Forest Marble and Bradford Clay.	1. to 5. Great Oolite (upper zone) Northampton Sand, the equivalent of Lower zone of Great Oolite and part of Inferior Oolite.	5, 4. Great Oolite Clays. Great Oolite Limestone. Upper Estuarine series.	5. Upper Shale and Sandstone (Upper Estuarine).
4. Great Oolite with Stonesfield Slate at the base.		2, 1. Inferior Oolite Limestone or Lincolnshire Oolite, with Collyweston Slate at the base. Northampton Sand, including Lower Estuarine Series.	2. to 4? Scarborough Limestone. Middle Shale and Sandstone with Moorland coals (Middle Estuarine). Millepore Bed. Lower Shale and Sandstone (Lower Estuarine).
3. Fuller's Earth.	Upper Lias Clay.		
2. Inferior Oolite.			
1. Midford Sands.			2, 1. Dogger Series.
Upper Lias Clay.		Upper Lias Clay.	Upper Lias Clay.

[1] See Note on previous page.

[2] The classification in these districts is mainly due to the researches of Mr. J. W. Judd, Prof. Morris, and Mr. S. Sharp.

MIDFORD SANDS.

The term Midford Sands was given in 1871 by Prof. Phillips to the Sands which occur between the Upper Lias Clay and the Inferior Oolite. The fauna of the Sands connects them as closely with the Lias as with the Oolites, and in their lithological characters they exhibit no very marked break; they are transitional, but perhaps more nearly allied to the sandy Oolite above, and therefore it is well to place them with the Oolitic series. In some localities the passage into the Lias appears to be very gradual, and in others the passage into the Oolites; but as a rule the base of the sandy beds is indicated by a line of springs thrown out by the Lias clays, and by a marked feature in the conformation of the ground.

Considerable palæontological changes, and some mineralogical changes, take place when the beds are traced across the country; and although the sandy condition prevails generally in the same position above the Upper Lias clay from Yorkshire into Dorsetshire, and the beds may strictly be termed homotaxeous, yet in places they partly represent other formations, and different names have been given to the series.

Thus Prof. Phillips remarks that in the long range from the coast of Dorsetshire to the coast of Whitby the character of the lower sand varies, and especially in colour. Through Oxfordshire, Rutland, Lincoln, and the southern part of Yorkshire, it is a very dark brown ferruginous rock, whence it is often called 'gingerbread stone,' frequently enclosing shelly concretions (Banbury), occasionally enveloping beds of limestone, and sometimes (Northampton, Rockingham) interlaminated by white beds of oolite. In some places, especially in Lincolnshire, it consists of an alternating series of white

and brown sand. Ironstone occurs in Northamptonshire and Oxfordshire.

We therefore have the Midford Sands of Dorsetshire, Somersetshire, and Gloucestershire; the Northampton Sands in the Midland Counties (which partly represent the Inferior Oolite and partly the Great Oolite); and in Yorkshire the sands beneath the Dogger (Blue Wick Sands), seen at Peak, Blue Wick (or Wyke) Bay, having a thickness of upwards of 50 feet. (See p. 177.)

It is only right to mention that Prof. Buckman considers the Dorsetshire sands to represent (palæontologically) portions of the Inferior Oolite of Gloucestershire; and that Mr. Judd has observed that the Northampton Sands sometimes rest on an eroded surface of the Upper Lias Clay,[1] a feature which Mr. Moore has noticed locally between the Midford Sands and Upper Lias, near Yeovil.

Midford is a little hamlet about three miles south of Bath, and it was there that William Smith first studied the Sands, and called them the 'Sand of the Inferior Oolite.'

They are very well developed at Nailsworth and Frocester, and the names of these places have been locally used to designate the Sands.

They consist of micaceous yellow sands, with occasional beds of concretionary sandstone or sandy limestone called 'sand bats' or 'sand burrs,' which sometimes contain organic remains: and they are capped by a brown marly iron-shot limestone, one to three feet in thickness, which yields numerous species of Ammonites, Belemnites, and Nautili, whence the bed has been termed by Dr. Wright the 'Cephalopoda-bed;'[2] while the series has been termed the 'Ammonite sands' by Mr. Hull.

[1] He states that as yet we have no *conclusive* evidence that any part of the Northampton Sand represents the Midford Sand.

[2] Dr. Wright termed the series 'Upper Lias Sands.'

Amongst the fossils *Ammonites Jurensis* is conspicuous: hence the formation has been termed the zone of *A. Jurensis* by Dr. Wright.

Rhynchonella cynocephala is another characteristic fossil: hence the term 'Cynocephala stage' used by Mr. Lycett.

The sands contain also *Ammonites radians*, *A. hircinus*, *A. variabilis*, *A. Aalensis*, *Cucullæa*, *Gervillia Hartmanni*, &c.

The fossils belong partly to the Lias and partly to the Inferior Oolite, and Prof. Phillips has well observed that 'before the Liassic life has come to an end, the Oolitic life has begun.'

That this change was not contemporaneous over the area embraced by Gloucestershire, Somersetshire, and Dorsetshire, seems to be borne out not only by palæontological differences, but by the varying thickness and occasional entire disappearance of the Midford Sands themselves.

To the east of Bridport Harbour there is a magnificent coast-section of the Sands, which there attain a thickness of probably 200 feet. On the other side of the Harbour the Sands likewise occur, overlaid almost directly by the Fuller's Earth, as the Inferior Oolite is extremely thin.

The beds are well exposed in the neighbourhood of Sherborne (140 feet) and Yeovil. They cap the summit of Glastonbury Tor and Brent Knoll (Cephalopoda-bed).

In Somersetshire, south of the Mendips, the thickness of the sands is about 160 feet.[1] North of the Mendips the thickness is very variable, and the sands disappear entirely in places. At Bath their thickness is about 40 feet; they have been well exposed in the tunnel under Combe Down.

In Gloucestershire the Sands and Cephalopoda-bed are persistent, and have a thickness of from 30 to 40 feet. The Cephalopoda-bed is sometimes bored by *Lithodomus*.

[1] Called 'Brim Sand' at Ham Hill, near Yeovil.

NORTHAMPTON SANDS AND LOWER ESTUARINE SERIES.

These beds consist of sand and sand-rock, containing much iron-ore, and having a thickness of from 20 to 80 feet.

Mr. S. Sharp has noted the following divisions of the beds in the Northampton district:—

	Feet
4. White or grey sand,[1] and sandstone sometimes quarried for building-stone, containing a plant-bed (*Lower Estuarine Series*)	12
3. Thin beds of ferruginous sandstone and shelly calcareous beds—very variable, being sometimes entirely calcareous, at others consisting of white sand and sandstone	30
2. Coarse oolitic limestone	4
1. Ironstone-beds containing *Rhynchonella variabilis, R. cynocephala, A. bifrons*	35
Upper Lias Clay.	

At Banbury the beds are only 12 feet in thickness.

Amongst other fossils from the Northampton Sands are:—*Avicula Braamburiensis, Gervillia acuta, G. Hartmanni, Hinnites abjectus, Lima duplicata, Ostrea gregaria, Pecten personatus, P. demissus, Astarte elegans, Cardium Buckmani, Ceromya Bajociana, Cucullæa cancellata, Trigonia costata, Terebratula perovalis, Nerinæa cingenda, Belemnites giganteus*, and *Ammonites Murchisonæ.*

Amongst the localities where the beds may be observed are Kingthorpe, Northampton, Duston (slaty beds), Blisworth, and Gayton.

The Ironstone-beds yield a number of fossils, many of them, as Mr. Sharp points out, cast, as it were, in iron, so that the introduction of the ore must have taken place subsequently by infiltration and replacement.

The ore yields 40, and sometimes 55, per cent. of pig-

[1] Clay-beds in this series have been worked for Terra-cotta in the neighbourhood of Stamford. Concretionary masses of sandstone called 'Pot-lids' are met with in the sands.

iron. It is worked at Duston, Blisworth, Gayton, Wellingborough, Cranford, Stamford, &c.

The Northampton sands include the Lower Estuarine series of Mr. Judd, which embraces the brown and white sands with argillaceous beds and plant-remains that occur above the fossiliferous Ironstone-beds.

In the northern part of Oxfordshire and south Northamptonshire, the Northampton Sands are considered by the Geological Survey (chiefly through Mr. Judd's investigations) to be the equivalent of the lower zone of the Great Oolite and part of the Inferior Oolite; while in the northern part of Northamptonshire and in Lincolnshire they include the Lower Estuarine series, and occur beneath the Collyweston Slates and Lincolnshire Limestone (Inferior Oolite).

The Northampton Sand forms a rich soil.

Origin of the Northampton Sand.—The following conclusions as to the origin of the Northampton Sand and Iron-ore, which have been so carefully worked out by Mr. Judd, may be introduced here, as they may serve to throw light on the origin of similar deposits of other periods :—[1]

We find, in what is now the Midland district of England, and at a period separated by a long interval of time from that of the last deposit in the area, the Upper Lias Clay, that a number of considerable rivers, flowing through the Palæozoic district lying to the north-west, formed a great delta. Within the area of this delta the usual alternations of marine, brackish-water, and terrestrial conditions occurred, and more or less irregular accumulations of sand or mud, in strata of small horizontal extent, took place. Subsequently, and probably in consequence of the gradual depression of the area, the conditions were changed, and in an open sea of no great depth, by the abundant growth of coral reefs and the accumulation of dead-shell banks during enormous periods of time, the materials of the great deposits of the Lincolnshire Oolite limestone were formed. On a re-elevation of the area the former estuarine conditions were also reproduced, and similar deposits, but of an argillaceous rather than an arenaceous character, were formed. Confining our attention to the earlier

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[1] Geology of Rutland, &c. (*Mem. Geol. Surv.*)

of these two estuarine series, that of the Northampton Sand, we must imagine the beds as being carried down to great depths in the earth by the deposition upon them of the superincumbent strata. But at the same time another most important cause has come into operation, namely, the passage through some portions of the rock of subterranean water containing carbonate of iron in solution. By this agent carbonate of iron was deposited in the substance of the rock, while portions of the siliceous and other materials were dissolved; and these entering into new combinations, were in part re-deposited in the mass of the rock in the form of oolitic grains, and in part, probably, carried away in solution. During the existence of the beds under a great pressure of overlying rocks, they would likewise become consolidated and jointed. These metamorphic processes would probably take place with extreme slowness, and may possibly still be going on, where the rock remains deep-seated in the earth; by their means portions, greater or less, of the sandy strata, but always those resting immediately on the impervious Upper Lias Clay, would be gradually converted into solid and jointed rock beds, composed principally of carbonate of iron. The next stage in the course of alteration in these rocks would commence when, by the action of denudation, portions of them were brought again near to the surface, so as to be traversed by the atmospheric waters, entering them as rain and passing away from them as springs. The action of this water is to remove the carbonic acid and soluble salts, to change the protoxide of iron into hydrated peroxide, and to redistribute it in such a manner as to produce the remarkable cellular structure of the rock, and also the mammillated, botryoidal, and sculptured surfaces. Finally, by mechanical, as distinguished from chemical, subaërial denudation, the beds of Northamptonshire iron-ore nearest the surface are disintegrated and broken up, and the softer and less ferruginous portions to some extent carried away in suspension, and thus deposits, composed of the harder and denser materials, formed, constituting the bed usually worked as an iron-ore. (J. W. Judd.)

INFERIOR OOLITE.

Under Oolite. (Smith.)
Bastard Freestone.

The Inferior Oolite consists of buff-coloured sandy oolitic and iron-shot limestone, with occasional beds of compact limestone. It is generally darker in colour than the Great Oolite.

At Leckhampton Hill it admits of the following divisions :—

6. Upper Ragstone and Clypeus bed	38 feet	—Zone of *Ammonites Parkinsoni.*
5. Lower Ragstone with *C. Plotii.*		
4. Upper (flaggy) Freestone (unfossiliferous)	34 „	„ „ *Humphresianus.*
3. Oolite Marl	7 „	
2. Lower Freestone	147 „	„ „ *Murchisonæ.*
1. Pea Grit	38 „	

The Pea-grit (according to Mr. Hull) is composed of flattened spheroidal masses about the size of a pea, and one fourth or one fifth of an inch in diameter. Many of the ovules consist of layers of carbonate of lime, aggregated around some organic or inorganic fragment: some appear to be small rolled fragments of limestone. This division is very fossiliferous.

The Lower Freestone yields the building-stone quarried at Bourton, Broadway, Guiting, Stanway Hill, Cleeve Cloud, Leckhampton Hill, Painswick Hill, Birdlip, Sheepscomb Hill, Hellcomb, Lyreford, Brockhampton, and Longborough.[1] The freestone is largely composed of comminuted shells. The Upper Freestone, also quarried, is oolitic. The fossils include Echinoderms, *Nucleolites* (*Clypeus*) *sinuatus*, *Acrosalenia*, *Hemipedina*; Molluscs, *Gryphæa Buckmani*, *Pholadomya fidicula*, *Trigonia costata*, *Ceromya concentrica*, *Ostrea Marshii*, *Myacites musculoides*, *Terebratula fimbria*, *T. globata*, *T. plicata*, *Rhynchonella tetrahedra*, *R. spinosa*, &c.

Beds 5 and 6 have locally, in the Cotteswold Hills, been divided into palæontological zones by Mr. Lycett and Dr. Wright: thus in descending order they are represented by the Pholadomya Grit, the Trigonia Grit (*T. costata*), the Gryphite Grit (*G. subloba*), the Chemnitzia Grit (*C. procera*): all these have been collectively grouped as the Spinosa

[1] The stone when first removed can usually be cut by the saw; it hardens upon exposure.

stage, characterized by *Rhynchonella spinosa*. No. 3 has been termed the Fimbria stage, being characterized by *Terebratula fimbria*.

The beds which rest on the Pea-grit are, according to Mr. Hull, frequently pierced by *Lithodomus attenuatus*: the upper bed of the Ragstone is also bored by Lithodomi.

Burton Bradstock is so well known as a locality for Inferior Oolite fossils, that it may be interesting to give the following section afforded by the quarries in the zone of *Ammonites Parkinsoni* which was taken at this locality by Dr. Wright:—

	Feet	in.
5. Coarse ferruginous iron-shot oolite, containing many fossils: *Ammonites Parkinsoni, A. Truellei, A. subradiatus, Ancyloceras annulatum, Astarte obliqua*	3	0
4. Thin-bedded oolitic limestone, with few fossils	1	6
3. Brachiopoda-bed; a rich shelly oolite, containing immense numbers of *Terebratula sphæroidalis*	1	0
2. Thin-bedded oolitic limestone; few fossils	1	8
1. Coarse brown oolitic limestone	2	0

The quarries at Halfway House, between Sherborne and Yeovil, and those near Bradford Abbas, have yielded many fossils.

The two well-defined divisions of the Inferior Oolite of the south of England are thus described by Dr. Holl:—

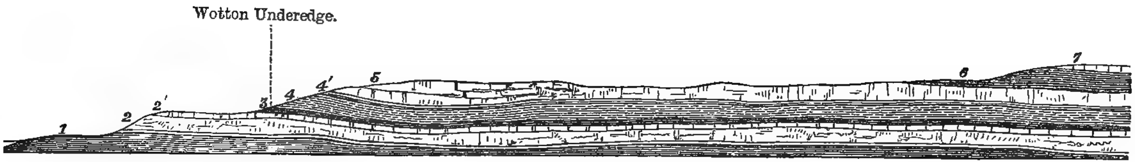
> *Upper Ragstone*, consisting of light-coloured, coarse-grained, thin-bedded or flaggy oolite, containing few fossils, and those chiefly in the form of casts.
>
> *Lower Ragstone*, consisting of hard, brown, ferruginous limestone, often much speckled with ovoid grains of peroxide of iron, and abounding in fossil remains.

In the neighbourhood of Bath the Inferior Oolite is about 60 feet in thickness.

Prof. Hull observes that this formation, which in the Cotteswold Hills attains a thickness of 264 feet, is represented in the neighbourhood of Woodstock by only 5 to 10

FIG. 15.—*General section of the Cotteswold Hills.*

(Prof. A. C. Ramsay.)



7. Great Oolite.
6. Fuller's Earth.
5. Inferior Oolite.

4'. Cephalopoda Bed } Midford Sands.
4. Sands
3. Upper Lias.

2'. Rock-bed
2. Sands and Clays } Middle Lias.
1. Lower Lias.

feet of the highest member of the series. At Sarsden the thickness is about 20 feet; at Fawler, near Stonesfield, 10 feet; at Enstone there is only a trace; and along the valley of the Cherwell it is altogether absent.

The Inferior Oolite forms good building-stone at Dundry Hill and to the south of the Mendips; the quarries at Doulting,[1] those near Yeovil and at Ham Hill are well known. At Ham Hill the stone is chiefly composed of comminuted shells. It has also been worked at Stinchcombe, Wotton Underedge, and other places in the Cotteswold Hills.

The soil is reddish-brown and brashy; the character of the ground is hilly, and sometimes barren, but where the soil is deep it is fertile.

Dogger Series.

Resting upon the Alum Shale (Upper Lias) of Yorkshire is the series known as 'Dogger.'

The Dogger[2] is a sandy and oolitic ironstone, but the series is sometimes taken to include not only the Dogger proper, but the grey and yellow (Blue Wick) sands which underlie it.

The Upper Lias seems to pass gradually upwards into the beds above, which are classed as follows:—

		Feet
Dogger Beds.	Yellow sandstone and ironstones (Dogger) including the Nerinæa Bed (*N. cingenda*)	30
	Yellow sands and Sandstone, with Terebratula Bed (*T. maxillata*)	20 to 25
Blue Wick Sands.	Grey sands and sandstones, containing a Serpula Bed, and Lingula Bed (*L. Beanii*)	20 to 25

Upper Lias (passage beds), Sandy shales yielding *Ammonites striatulus* (Striatulus Beds).

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[1] This stone was used in the construction of Wells Cathedral and Glastonbury Abbey.

[2] It is not certain whether the Dogger (sometimes termed the Scar of

The Dogger itself has been much worked for iron-ore. The magnetic iron-ore of Rosedale is worked in this series; and Prof. Phillips considers that this ore, and those of Thirsk and Kirkham, are the equivalents of the Northamptonshire iron-ores.

The Dogger is placed on the horizon of the Inferior Oolite, so that the sands below are homotaxeous with the Midford Sands.

Lower Shale and Sandstone (Yorkshire).

LOWER ESTUARINE BEDS.

This series, which rests upon the Dogger, comprises alternating beds of sands, sandstone, and shale, with oolitic ironstone, and much carbonaceous matter, and attains a thickness of 280 feet. The beds, as a rule, contain no marine shells, but many plant-remains.

The 'Great Sandrock,' 50 to 100 feet, occurs at or near the base of the series: it is largely used for building-stone.[1] Mr. Hudleston observes that the group thins out towards the south and west of the Oolitic area; it, however, constitutes a large portion of the Staintondale Cliffs, where, in certain layers of nodular ironstone, many species of ferns are nicely preserved. The beds appear in the cliffs from Robin Hood's Bay to Huntcliff.

Millepore Bed (Yorkshire).

This bed, so named from the occurrence of *Cricopora* (*Spiropora*) *straminea*, occurs as a limestone in Gristhorpe

Whitby) has received its name from the lines of nodules, so characteristic of it, or from the peculiar appearance which the rock assumes owing to the rounding off of the huge oblong blocks, produced by the arrangement of the jointing. (W. H. Hudleston.)

[1] Whitby Abbey was constructed of this stone.

Bay; nearer Scarborough it is obliquely laminated and arenaceous, and it is still more sandy at Cloughton Wyke. Dr. Wright correlates the Whitwell limestones of the Howardian Hills with this bed, and the slaty limestones of Brandsby appear to be on the same horizon. It is from 12 to 30 feet in thickness.

It is continued in the Cave Oolite and Lincolnshire Limestone, and, as Mr. Hudleston considers, may therefore, with the Whitwell and Crambeck Limestone, be the chief representative of the Inferior Oolite in Yorkshire.

The bed yields *Lima duplicata*, *Gervillia Hartmanni*, *Pinna cuneata*, *Ceromya Bajociana*, &c. Most of the fossils have been obtained from Sycarham, near Cloughton Wyke.

Middle Shale and Sandstone (Yorkshire).

Middle Estuarine Beds.

This group of Shales and Sandstones (Block Sand rock), from about 40 to 100 feet in thickness, contains many plant-remains, ironstone-nodules, seams of coal, and sometimes jet.

The thickest seam of Moorland coal varies from a few inches to 18 inches in thickness. Mr. Hudleston observes that it is of little economic value, but it is remarkable for its persistency over a very large area, extending from the coast inland as far as Castleton and Coxwold.

At Gristhorpe the plant-bed has yielded many cycads, and ferns such as *Sphenopteris*, *Pecopteris*, *Neuropteris*, &c., also *Equisetites columnaris*.

Scarborough Limestone.

This deposit comprises a series of blue and grey limestones (= 'Grey limestone' of Dr. Wright), with occasional shales and mudstones, 20 to 60 feet in thickness.

The beds yield *Belemnites elongatus*, *Avicula Braamburiensis*, *Gervillia acuta*, *Perna rugosa*, *Pecten lens*, *Pinna cuneata*, *Trigonia costata*, *Gresslya peregrina*, &c. Many species have been obtained at Hundale.

According to Mr. Hudleston the beds are feebly developed at Gristhorpe Bay (8 feet), but make a better show at White Nab and in Scarborough Bay.[1]

Stonecliff Wood Series.—This series, named by Mr. Hudleston, consists of sands containing towards the base and upper part intercalated beds and lenticular masses (pot-lids) of arenaceous and siliceous limestone; it is altogether about 30 feet in thickness.

The beds form a sort of escarpment facing the Derwent Valley. Some of the stone beds are used for building purposes.

The fossil remains, including *Avicula Braamburiensis*, *Gervillia acuta*, *Perna rugosa*, and *Mytilus sublævis*, seem to link the beds with the Scarborough Limestone.

Collyweston Slate.

At Collyweston, near Stamford, certain fissile calcareous sandstones, or sandy limestones, which, after exposure, split up horizontally and form flagstones, have been quarried for roofing-purposes during the past four hundred years, and are termed the Collyweston Slates.

These beds overlie the Northampton Sands. The surfaces of the slates, as mentioned by Mr. Judd, exhibit the proximity of the shore, in ripple-markings, worm-tracks, and burrows, as well as by numerous plant-remains.

The fossils of the Collyweston Slates include *Pecten pumilus*, *Avicula Braamburiensis*, *Pinna cuneata*, *Gervillia*

[1] Mr. Sharp considers these beds to be in all probability nearly synchronous with the Lincolnshire Limestone (Inferior Oolite). Phillips placed them with the Great Oolite.

acuta, *Trigonia costata*, *Pholadomya fidicula*, *Ceromya Bajociana*, *Goniomya literata*, *Perna rugosa*, &c.

These slates, according to Prof. Morris, may partly represent the beds which overlie the Dogger in Yorkshire (the Lower Shale and Sandstone).

They are quarried at Collyweston, Wittering, Easton, Deene, and Kirby.

The work of quarrying is carried on only in winter, for, if dried by the summer sun and wind, the rock hardens and will not split. The holes are blocked up in spring, and the quarrymen then employ their time in the preparation of the 'slate.' The splitting is caused by the presence of organic remains. (Phillips.)

Lincolnshire Limestone.

Overlying the Collyweston Slates of Stamford (to quote Prof. Morris) there is a series of cream-coloured marly limestones, as well as oolitic rag-stones of some thickness (about 75 feet), as seen in the quarries near Stamford, where they yield the so-called 'Stamford Marble.' They occur also at Barnack (Barnack Rag[1]), Casterton, Geeston, Ketton (freestone[2]), Collyweston and Morcot, Denton, Ponton, Corby, Weldon, &c., where they furnish valuable building-stone.

The beds contain, among Mollusca, *Nerinœa cingenda*, *Ceromya Bajociana*, *Pholadomya fidicula*, *Pinna cuneata*, *Mytilus Sowerbyanus*, *Astarte elegans*, *Pecten pumilus*, *Terebratula submaxillata*, &c.; also the Plants *Pecopteris*, *Pterophyllum*, and *Palœozamia*.

These, together with the Collyweston Slates, are placed on the horizon of the upper part of the Inferior Oolite by

[1] The Barnack Rag is said to have been quarried by the Romans, and the quarries exhausted four hundred years ago. (Sharp.)

[2] The Ketton Stone was used in the construction of Peterborough and Ely Cathedrals.

Mr. Judd and Mr. Sharp. This position of the Lincolnshire limestone was first hinted at by the Rev. P. B. Brodie and Dr. Lycett.

In Lincolnshire (whence the name) the oolitic limestones which constitute the formation attain a thickness of about 200 feet: they thin out near Kettering. At Stamford the thickness is about 80 feet.

The beds are largely worked at Haydor and in the Railway-cutting near Grantham; also at Ancaster.

In the north-western part of Lincolnshire the Rev. J. E. Cross divides the beds as follows:—

Lincolnshire Limestone, 36 feet.
Santon Oolites, with soft ferruginous bed at base.

Mr. Judd considers that the Lincolnshire Limestone was deposited under moderately deep sea-water conditions, but there are evidences in its lower portion of littoral accumulations. (See p. 172.)

The soil is light and not very productive. The beds, besides being largely used for building-purposes, are burnt for lime.

At Oundle and Higham Ferrers the Northampton Sand is directly overlaid by the Upper Estuarine Series (base of Great Oolite).

FULLER'S EARTH.

The term Fuller's Earth is applied to a thick deposit of blue and yellow clay, divided near the middle, in some localities, by beds of rubbly limestone, called Fuller's Earth Rock. It is characterized by the presence here and there of beds of blue and yellow Fuller's Earth, a sandy clay, which is described by Mr. Bristow as usually of a greenish-brown or greenish-grey colour, sometimes blue. It is opaque, soft,

dull, with a greasy feel, and an earthy fracture. It yields to the nail, and affords a shining streak. It scarcely adheres to the tongue; becomes translucent when placed in water, and falls into a pulpy impalpable powder, without forming a paste with it. The blue Fuller's Earth is frequently of as good a quality as the yellow, for particular purposes, as in fulling coarse cloths, but the yellow is usually esteemed the better.

The general thickness of the veins is from 18 inches to 3 feet. If good, a vein 18 inches in thickness could be worked with profit, but not if of less thickness. Sometimes the vein stops suddenly; at others it gradually thins out.

Shafts were formerly sunk in the Fuller's Earth south of Bath to a depth of 20 or 30 feet, with levels. It was then much used in fulling at the cloth mills at Bradford-on-Avon, Frome, and in Gloucestershire. It is now, however, rarely if ever worked in the district.

The total thickness of the Fuller's Earth in Somersetshire is from 120 to 150 feet. Nodules of indurated marl sometimes occur in the lower beds.

The Fuller's Earth is largely developed in Dorsetshire (400 feet), but entirely disappears when traced beyond Gloucestershire; it does not extend beyond Burford on the borders of Oxfordshire. In Gloucestershire it has a thickness of 128 feet at Wotton Underedge, 70 feet at Stroud and Sapperton Tunnel, and occurs as a thin band at Cheltenham. The upper layers are frequently interstratified with beds similar to Great Oolite. (See fig. 15, p. 176.)

Amongst the fossils of the Fuller's Earth may be mentioned *Ostrea acuminata*, *O. rugulosa*, *Avicula echinata*, *Pecten vagans*, *P. lens*, *Pholadomya truncata*, *Goniomya literata*, *Homomya Vezelayi*, *Isocardia concentrica*, *Ceromya plicata*, *Terebratula globata*, *T. perovalis*, *T. ornithocephala*, and *Rhynchonella media* (*varians*).

Mr. R. Tate has estimated the number of species at 93; he regards the deposit as the uppermost zone of the Inferior Oolite.

The Fuller's Earth throws out copious springs, and causes numerous slips on the declivities of the hills around Bath.

Stonesfield Slate.

The Stonesfield Slate comprises shelly oolites, gritty limestones, and laminated calcareous sandstones or flags, which, splitting readily along the planes of bedding, produce the so-called slates of Stonesfield. In some places the Stonesfield Slate passes into an oolitic freestone, as near Burford and Windrush. False-bedding is often met with.

The formation is rich in fossil Plants, Corals, Echinoderms, Molluscs, Fishes, Reptiles, and Mammals.

The Mammals include the *Amphitherium*, *Phascolotherium*, and *Stereognathus*; the Reptiles include *Megalosaurus*, *Teleosaurus*, and *Testudo*; the Fishes include *Pholidophorus*, *Lepidotus*, *Pycnodus*, *Ganodus*, *Hybodus*, *Nemacanthus*, *Ceratodus*, &c. Amongst the Mollusca are *Rhynchonella concinna*, *Trigonia impressa*, *Gervillia acuta*, *Ostrea acuminata*, &c. The plant-remains include Algæ, Ferns, Cycads, and Conifers.

The flaggy beds are quarried in the Evenlode Valley, at Sarsden, Woodstock, on Sevenhampton Common, Eyeford, &c.; and the freestone beds at Burford and Windrush. Thus, as Mr. Hull remarks, in some places the beds yield 'slates' for roofing-purposes, in others blocks of stone for building.

The deposit worked for slates is sometimes only a foot in thickness, but it generally consists of two fissile beds of a buff-coloured or grey oolitic limestone called *pendle*, each about two feet thick, separated by a bed of loose calcareo-siliceous sandstone called *race*, about the same thickness.

Concretions are frequent in the latter, and are called *whim-stones* or *pot-lids;* they are partially oolitic, sometimes blue in the centre, and vary from six inches to two feet in diameter; their form is generally that of a flattened sphere; they do not break concentrically, but into parallel planes; and they often contain shells. The pendle, after being quarried, is suffered to lie exposed to the action of a winter's frosts, and the blocks being then struck on their edge with a mallet, freely separate into slates sufficiently thin to afford a light material for roofing. The quarries are principally situated in the valley immediately to the south of Stonesfield village, which branches off eastwards from that of the Evenlode. The mode of working is by driving horizontal galleries about six feet high into the side of the hill, and then extracting the two strata of pendle laterally, piling up the refuse masses of the intermediate bed of race, so as to support the roof: deep perpendicular shafts communicate with these galleries. These workings have been carried on from remote times to a considerable extent, so that both sides of the valley are completely honey-combed by them. Beautiful plumose stalactites are often found in the fissures of the rock, and are called by the workmen, from an obvious though coarse analogy, tallow. (Conybeare and Phillips.)

Upper Estuarine Series.

Above the Lincolnshire Oolite is a series of blue and grey laminated marls, clays, and shales, 15 to 30 feet in thickness, containing wood and other plant remains, and species of marine and freshwater mollusca. This has been termed by Mr. Judd the Upper Estuarine series. At the base is a ferruginous band rich in fossils.

Mr. Sharp observes that the Upper and Lower Estuarine series occur together in vertical juxtaposition throughout a

large part of Northamptonshire and in Oxfordshire. In Oxfordshire he observes that the Upper Estuarine series is traceable to the Stonesfield Slate, and the difficulty of separating the two Estuarine series led formerly to the Northampton sand (Lower Estuarine) being regarded as the equivalent of the Stonesfield Slate. Among the fossils are species of *Pholadomya*, *Modiola*, *Ostrea*, *Cyrena*, *Unio*, &c.; remains of *Cetiosaurus* also occur in the beds.

All the characters presented by the Upper Estuarine series, according to Mr. Judd, point to the conclusion that they were accumulated under an alternation of marine and freshwater conditions, such as occurs in the estuaries of rivers.

In the north-western part of Lincolnshire the Rev. J. E. Cross has described clayey beds about 40 feet in thickness as resting upon the Lincolnshire limestone. They contain *Ostrea subrugulosa*, &c.; also fish-remains.

The Clays in this series are worked for brick-making. The soil is comparatively barren.

GREAT OOLITE.

The Great or Bath Oolite consists of a series of shelly limestones (rags) and fine oolites or freestones, often exhibiting much false-bedding, and generally of a yellowish-white colour.

The Great Oolite is rich in univalve mollusca, such as *Alaria*, *Cylindrites*, *Nerinæa Voltzii*, *Nerita*, *Patella rugosa*, *Purpuroidea Morrisii*; amongst the bivalves are *Ceromya*, *Cypricardia*, *Gervillia*, *Trigonia costata*, *Pholadomya*, *Tancredia brevis*, *Astarte excavata*, *Arca*, *Ostrea gregarea*, *Pecten lens*, *Lima cardiiformis*, and *Opis lunulatus*. Cephalopoda are not abundant. Amongst the

Brachiopoda are *Rhynchonella concinna*, *Terebratula perovalis*, *T. digona*, &c. The Coral, *Eunomia radiata*, is common near Bath.

The Great Oolite series in the neighbourhood of Bath was thus divided by Lonsdale :—

		Feet
Upper Rags.	1. Coarse, shelly limestones 2. Tolerably fine oolites 3. Tough, brown, argillaceous limestone	20 to 55
Fine freestones		10 to 30
Lower rags, Coarse, shelly limestones		10 to 40

The Bath stone, as is well known, hardens on exposure after it has been quarried. In its natural bed it is soft and moist, and Professor Ansted states that a cubic foot of Bath stone will absorb one gallon of water. According to E. Owen, who wrote in 1754, 'there is no stone that differs so much in its bed, and after it has been wrought and exposed to the air, as the *Bath* free-stone. While it is in the ground, it is soft, moist, yellowish, and almost crumbly; and it seems very little more than congealed sand, and that not well concreted together. But when it has been some time exposed to the air, and is thoroughly dry'd, it becomes white, hard, firm, and an excellent stone.'

The beds are largely quarried, or mined, near Bath (on Combe, Bath Hampton, and Farleigh Downs), at Box and Corsham.

Some of the beds, called Weather Stones (brown shelly oolitic limestones), are specially valuable for plinths, cornices, &c.; the Scallet is of superior quality, being of very fine texture. The absence of fossils renders the rock more valuable as a freestone.

At Minchinhampton there are extensive quarries (Hampton stone), showing 30 to 40 feet of rock. The beds are also worked at Chalford, Brimscombe, Burley, &c. The soil is a loose stone-brash.

In the district south of Frome the Great Oolite thins away entirely, and is represented partly by the Forest Marble, and perhaps also by the Fuller's Earth.

The Great Oolite generally forms a well-marked feature in Gloucestershire and the borders of Oxfordshire.

At Coln St. Denis the beds, consisting of white limestone resting on marls, have a thickness of about 145 feet. At Burford the beds have a thickness of about 100 feet.

The upper rock-bed, according to Mr. Hull, is frequently pierced by Lithodomi, and it also affords interesting evidence of having been consolidated contemporaneously with its deposition. Occasionally he has noticed beds of conglomerate formed by waterworn fragments of the underlying limestone.

On Minchinhampton Common, where the beds have yielded a rich collection of fossils to Mr. Lycett, there appears to be no positive line of separation between the Great Oolite and the Forest Marble.

Other fossiliferous localities are near the Seven Springs, North Leach, Burford, and Sherborne Park (Gloucestershire).

At Sapperton Tunnel Mr. Hull estimates the thickness of the limestones at 20 feet. He observes that in the country near Woodstock, at Wychwood Forest, &c., the beds are blue when reached at some depth, but they weather white, and are called white limestones. The limestones are not usually oolitic, but compact and sometimes marly.[1] The beds contain plant-remains and jet, and have a thickness of from 20 to 30 feet.

[1] Mr. Judd has pointed out that when dug at great depths or otherwise obtained at points where they have not been exposed to atmospheric influences, all the Oolitic rocks exhibit an almost uniform deep-blue tint, which is apparently communicated to them by a diffusion through their substance of small quantities of sulphide of iron.

Great Oolite Limestone.

The term Great Oolite Limestone is used in Lincolnshire and the northern part of Northamptonshire because the Great Oolite series is divided into :—

3. Great Oolite Clay, about 20 feet in thickness.
2. Great Oolite Limestone „ 25 „ „ „
1. Upper Estuarine series (Stonesfield Slate).

The Great Oolite Limestone, as described by Mr. Judd, consists of alternate beds of white limestone and marly clay, with seams made up of the shells of small oysters. Oolitic structure is seldom developed.

Among the fossils are *Ostrea subrugulosa*, *O. Sowerbyi*, *Homomya gibbosa*, *Terebratula maxillata*, *Rhynchonella concinna*, *Clypeus Mülleri*, *Isastrea*, also bones of *Cetiosaurus*, and some fish-remains.

Near Banbury, according to Mr. Beesley, it is a white compact earthy limestone, often blue within, and seldom oolitic in structure; moreover, it never assumes the character of a freestone. It is chiefly used as limestone and road-metal. The compact limestones are sparingly fossiliferous, but the intervening shaly or marly beds afford a number of species, many of which have been obtained at Tadmarton.

In Northamptonshire the limestone beds are worked for building-purposes and lime-burning, at Kettering, Higham Ferrers (Stanwick Ragstone), &c.

At Alwalton, near Peterborough, the stone takes a good polish, and is termed the Alwalton Marble. Flaggy beds occur also at Alwalton, Castor, &c.

Great Oolite Clay.

This clay, termed Blisworth Clay by Mr. Sharp, and Great Oolite Clay by Mr. Judd, occurs at the top of the Great

Oolite series in Northamptonshire, resting upon the white marly limestones (Great Oolite Limestone). Mr. Sharp has estimated its thickness at from 2 to 20 feet. He considers that the clay is not represented in Yorkshire, but doubtless answers to the Forest Marble and Bradford Clay of the south-west of England.

Mr. Judd describes it as a series of variegated, blue, green, yellow, and purplish clays, often containing bands of irregular whitish or pale-green calcareous concretions, and sometimes septaria.

It contains *Ostrea subrugulosa*, *O. Sowerbyi*, *Placunopsis socialis*, &c. In part the beds seem to be of estuarine character.

The clay is employed for brick-making at Bedford Purlieus, and New England, near Peterborough. At Bottlebridge, near Overton Longville, some ironstone has been raised. The soil is by no means fertile.

FOREST MARBLE.

The Forest Marble, so termed by William Smith from the Forest of Wychwood in Oxfordshire, consists of flaggy or fissile oolite, shelly limestone, and beds of clay, sand, and grit, displaying much false bedding. Prof. Hull remarks that owing to the rapid enclosure of Wychwood Forest many quarries have been opened, showing the lower beds (resting on the Great Oolite) to consist of false-bedded shelly oolite, splitting into slabs and flags, and composed of enormous quantities of broken oyster shells; they are about 30 feet in thickness. The higher beds consist of bluish clays and marls, with thin flagstones and roofing slates, from 20 to 30 feet in thickness.

Ripple-marks and worm-tracks abound on the surfaces of some of the beds. Fossil-wood occurs in a few localities.

Among the fossils are *Terebratula maxillata, Rhynchonella concinna, R. obsoleta, Pecten vagans, Ostrea acuminata, O. rugosa, Avicula echinata,* &c.; but none of these are peculiar to the formation.

In Dorsetshire the Forest Marble (according to Mr. Bristow) comprises beds of fissile limestone, divided by seams of clay, which attain a thickness of 450 feet. This disproportionate thickness was considered by Conybeare to be due to the Great Oolite being probably represented in the series.

The following divisions of the beds in Somersetshire and Wiltshire were made by Lonsdale:—

		Feet
Forest Marble.	6. Clay with occasional laminæ of grit	15
	5. Sand and Grit = Hinton Sand and Sandstone of W. Smith, at Charterhouse Hinton, near Bath . . .	40
	4. Clay, with thin slabs of stone, and laminæ of grit . .	10
	3. Shelly limestone or coarse oolite	25
	2. Sand or sandy clay and grit	10
	1. Bradford clay.	

Between Cirencester and North Leach the beds have a thickness of about 40 feet. In Oxfordshire the thickness averages 25 feet. At Blenheim Park the thickness is 14 or 15 feet. The Forest Marble also occurs near Peterborough.

Some of the beds furnish coarse roofing-slates and flagstones, as at Fairford and Chavenage.

Near Milborne Port the beds are worked at Bowden, and known as Bowden Marble; they are also quarried at Wincanton.

Mr. Bristow informs me that at Long Burton in the neighbourhood of Sherborne (Dorset) beds of Forest Marble are sometimes polished for ornamental purposes.[1]

[1] Sometimes called Yeovil marble.

Prof. Buckman remarks that slabs of Forest Marble are of great value for forming the sides of piggeries and cattle-sheds. The smaller pieces broken up form a very durable material for road-making. Some of the thicker blue-centred slabs are used for building purposes, for which (especially in the shape of rough ashlar) they are admirably adapted, as they readily form even courses of a somewhat regular thickness. As a soil, the Forest Marble is usually poor, but capable of great improvement by draining and cultivation.

Some of the flaggy beds are used for paving; and at Brotherhampton, south of Bridport, the more calcareous beds have been burned for lime.

Bradford Clay.

This is a deposit of pale-grey clay, slightly calcareous, containing seams of tough brown limestone and calcareous sandstone, identical in character with beds sometimes interstratified with the lower portion of the Forest Marble.

It is, however, of sufficient importance locally to receive a separate name from its occurrence at Bradford-on-Avon.

The greatest thickness of the Bradford Clay seems to be near Farleigh, where it is roughly estimated at from 40 to 60 feet. Where the Great Oolite has disappeared south of Frome, the Bradford Clay and Fuller's Earth come together, and it is not easy to separate the two; while, on the other hand, where the Bradford Clay is wanting it becomes difficult to distinguish the upper beds of the Great Oolite from the lowest of the Forest Marble.

A characteristic fossil, but one which also occurs in the Forest Marble, is the Bradford or Pear Encrinite, *Apiocrinites rotundus* (or *Parkinsoni*).[1] *Terebratula digona*, *T.*

[1] The fragments of the stalk and body of this Crinoid are called 'Coach-wheels' by the quarrymen.

decussata, and *Avicula costata* are also characteristic. Dr. S. P. Woodward obtained more than 100 species of marine animals from this formation in the neighbourhood of Cirencester.

Upper Shale and Sandstone. (Yorkshire.)

UPPER ESTUARINE.

This formation (as described by Mr. Hudleston) is remarkable for the quantity of hard siliceous rock, which is sometimes bedded with it, and sometimes occurs in enormous concretions or 'doggers'; it occasionally puts on the appearance of a quartzose grit. These doggers are probably the 'Crowstones' of Young and Bird, who state that of this material several of the ancient rude monuments have been made.

The beds rest on the Limestone series at Scarborough; under Wheatcroft the thickness is estimated at about 160 feet, and at Gristhorpe 80 feet.

Scarbroite (a hydrous silicate of alumina) occurs in crevices of the rocks.

Some of the clay-beds are worked near Scarborough for manufacture into tiles and drain-pipes.

CORNBRASH.

The Cornbrash consists of pale-coloured earthy and rubbly limestones, which have been well described as often of a pasty or chalky consistency. The beds, where not exposed to atmospheric influences, are mostly compact, blue in colour, and sometimes sufficiently hard to be used for rough building-purposes, as near Malmesbury.

The thickness of the formation is about 40 feet.

The fossils include *Ammonites Herveyi*, *A. macrocepha-*

lus, *Ostrea Marshii*, *Gresslya peregrina*, *Lima duplicata*, *Avicula echinata*, *Myacites securiformis*, *Terebratula obovata*, *T. maxillata*, *T. perovalis*, *Echinobrissus* (*Nucleolites*) *clunicularis*, *Holectypus depressus*, &c.

In the South of England it is never oolitic; it is well developed in Dorsetshire and Somersetshire.

In Oxfordshire, near Woodstock, the Cornbrash, 6 to 15 feet in thickness, consists of shelly limestones. Prof. A. H. Green has noticed that here and there clay-beds occur which cause the formation to swell out to more than double its average thickness; these clays are irregular, and never extend beyond small areas.

The Cornbrash occurs as a rather ferruginous limestone, in the Nene Valley, near Oundle, and Peterborough; here its thickness is about 15 feet. Rushden in Northamptonshire is a noted locality for fossils.

The Cornbrash of Yorkshire is a marly and sometimes oolitic limestone, overlaid by shale or 'clays of the cornbrash,' containing *Avicula echinata*. It is well developed in Newtondale (13 to 14 feet), where (says Mr. Hudleston) its ferruginous character tempted a speculator to work it for iron, while in a secluded nook of the same lovely valley there yet stands (1874) what was meant to have been a colliery—the shaft was sunk to a considerable depth, in the expectation of winning the real north-country coal! The shales vary from 8 to 15 feet in thickness, and seem to form a connecting link between the true Cornbrash and the Oxford Clay.

The Cornbrash is exposed at Gristhorpe and Scarborough, where it is from 5 to 10 feet in thickness.

It is a very shelly rock, and has yielded a large suite of species, for our knowledge of most of which we are indebted to Mr. Leckenby. These include *Ammonites Herveyi*, *Pecten vagans*, *Lima duplicata*, *Modiola cuneata*, *Terebratula obovata*, *Rhynchonella concinna*, &c.

The Cornbrash is used for road-mending, and for building walls, and is sometimes burnt for lime.

As the name implies, the soil in the South-West of England is well suited to the growth of corn; according to Prof. Buckman it contains more phosphate of lime than the subordinate Oolitic formations.

MIDDLE OOLITIC.

OXFORD CLAY.

CLUNCH CLAY AND SHALE. (Wm. Smith.)

The Oxford clay consists of dark-blue, yellowish or slate-coloured clay and bituminous shale. It effervesces with hydrochloric acid. It contains much iron-pyrites and selenite, and many septaria called 'turtle stones.'

Near its base is a bed of irregular calcareous sandstone of a concretionary nature and very fossiliferous, called the Kellaways (or Kelloway) Rock, by Smith, from Kellaways Bridge, near Chippenham, in Wiltshire. Although the clay derives its name from the county of Oxford, the Kellaways rock is not known in it.

The thickness of the clay varies from 300 to 600 feet; that of the Kellaways Rock is usually 8 or 10 feet in the South-west of England, and as much as 90 feet in Yorkshire.

Amongst the fossils are *Gryphæa dilatata*, *G. bilobata*,* *Modiola bipartita*, *Avicula inæquivalvis*,* *Trigonia clavellata*, *Nucula nuda*, *Belemnites hastatus*, *B. Oweni*,* *Ammonites Jason*, *A. cordatus*, *A. excavatus*, *A. vertebralis*, *A. Calloviensis*,* and *Ancyloceras Calloviensis*.*

* These belong to the Kellaways Rock.

Christian Malford, in Wiltshire, is a well-known locality for fossils of the Kellaways Rock.

Fossil wood has been found near Peterborough. Remains of *Ichthyosaurus*, *Plesiosaurus*, and *Pleiosaurus*, and of fishes, such as *Leptolepis*, and leaves of Zamia, are met with occasionally.

The Oxford Clay occurs near Weymouth, and extends across the Vale of Blackmore by Chippenham through Oxfordshire (350 feet) into Huntingdonshire.

Small hard nodules, called Kidney-stones, composed of reddish-brown clay with veins of Calc-spar, are frequently found in the Oxford Clay in the cliffs on the north shore of Weymouth.

In Northamptonshire the Kellaways Rock is represented by sands, sandstones, and clays. The clays are worked for brick-making at Oundle and other places.

The Oxford Clay forms the substratum of the western portion of the Cambridgeshire fens and those which border on Huntingdonshire; hence it has sometimes been called the *Fen Clay*.

The researches of Professors Sedgwick and Seeley have shown that at Elsworth, near St. Ives, dark-blue iron-shot limestone about fourteen feet in thickness occurs near the top of the Oxford Clay (see p. 199).

At St. Ives a somewhat similar rock occurs at a lower level. Near Bluntisham a rock resembling these is found; and at St. Neots rubbly rock occurs, which may be on the horizon of the Kellaways Rock.

The Oxford Clay has been reached in the Sub-Wealden boring, near Battle, at a depth of over 950 feet.

The Kellaways Rock is very remarkable on account of its occurrence over a great extent of country, although at the same time it is not a persistent stratum: it is not known in Somersetshire or Dorsetshire. It is found near Welling-

borough, Hackness, and Scarborough, and is sometimes known as the Hackness rock. In this district it contains clayey sandstone and ironstone, and the Killing Pits in Goathland Beck are considered to be the remains of rude mining operations in the beds. In Yorkshire the Oxford Clay (grey shale) attains a thickness of 150 feet.

The Oxford Clay is difficult and expensive to cultivate; it is mostly under permanent pasture. The old Forest of Braydon (Wilts) was situated on the Oxford Clay.

Septaria have been polished as marble at Weymouth, Melbury, and other places in Dorsetshire, where they are locally termed 'pudding-stone.'

The Clay has been largely worked for brick and tile-making near Peterborough, and other places.

Beds of bituminous shale and lignite have led to futile searches for Coal in many tracts where the Oxford Clay is exposed.

The Kellaways Rock is used for building purposes in some places, also for road-mending.

The Oxford Clay is a retentive formation, and to obtain well-water it is necessary to penetrate it. At Boston a well was sunk 478 feet in it and abandoned.

CORAL RAG.

The Coral Rag where most fully developed is divided into:—

Upper Calcareous Grit,
Coral Rag,
Lower Calcareous Grit.

In some localities the entire series is absent, or almost so, as in the Fen district, and as proved by the Sub-Wealden exploration in Sussex. This absence, which causes the Kime-

ridge and Oxford Clays to come directly together, by no means proves any unconformability, nor need we even infer the probability of one: the history of most calcareous rocks in Britain illustrates their frequent attenuation, and absence, for they occur, as it were, in great lenticular-shaped patches.

The Upper Calcareous Grit consists of ferruginous sand and clay, with occasional oolitic beds, attaining a thickness at Calne and Steeple Ashton of 20 feet.

The Coral Rag, or Coralline Oolite, includes beds of freestone—the Oxford Oolite—and rubbly oolite and clay, with beds of corals of the genera *Thecosmilia*, *Thamnastræa*, *Isastræa*, *Stylina*, &c. The thickness is sometimes 80 feet.

The Lower Calcareous Grit consists of sand with beds of calcareous grit and sandy limestone. It contains *Ostrea gregaria*. The thickness is 40 or 50 feet.

Other fossils in the series are:—*Pholadomya paucicostata*, *Myacites securiformis*, *Trigonia clavellata*, *Ostrea deltoidea*, &c. *Nerinæa Goodhallii* (sometimes upwards of a foot in length) is a characteristic fossil.

Most of the Corals retain the position in which they grew. In their forms (Lyell remarks) they more frequently resemble the reef-building polyparia of the Pacific than do the Corals of any other member of the Oolitic series.

The Coral Rag and Lower Calcareous Grit are well developed in Dorsetshire; the thickness of the series is 250 feet at Weymouth.[1] The Upper Calcareous Grit is feebly represented by a grey marly stone streaked with clay.

At Abbotsbury the Coral Rag contains a deposit of oolitic iron-ore (hydrous oxide of iron). A bed of pea-grit has been noticed by Mr. Damon in the Coral Rag near Osmington Mills, and Mr. Bristow has traced it near Todbere. At this last-named place and at Marnhull, large blocks of fine-grained oolite are quarried.

[1] This series has been termed the Weymouth sands and grit.

In Wiltshire the Coral Rag has been thus divided :—

	Feet
Upper Calcareous Grit, ferruginous sand and clay slightly oolitic .	20
Coral Rag, rubbly and shelly oolite, quarried for road metal and freestone, with beds of corals at the base	120
Lower Calcareous Grit, sands and calcareous sandstone . . .	50

Sometimes a bed of clay overlies the Lower Calcareous Grit.

At Steeple Ashton the Coral Rag is pisolitic. The Calcareous Grit is well shown at Seend. Oolitic iron-ore has been worked near Westbury.

In Oxfordshire the Coral Rag is divided into :—

	Feet
Upper Calcareous Grit, consisting of variegated sand and clay .	5
Coral Rag, oolitic shelly limestone and pisolite	10 to 25
Lower Calcareous Grit, hard grit and soft brown sands . .	20 to 80

To the north-east of Wheatley, in Oxfordshire, the Coral Rag and Calcareous Grit entirely disappear.

Prof. Seeley considers that in Huntingdonshire and Cambridgeshire the Coral Rag is represented by the Tetworth Clay. This rests on the Elsworth Rock, which may represent the Lower Calcareous Grit, and is surmounted by the Boxworth Rock, a hard, dark blue, flaggy and shelly limestone. Prof. Sedgwick has observed that the great area of fen-land, occupying the Bedford Level and a considerable portion of Lincolnshire, rests on a deposit of clay of great but unknown thickness. All the lower portion of this deposit belongs to the Oxford Clay, and the highest portion to the Kimeridge Clay; and there is no indication of any break of continuity between these formations.

In Yorkshire the following divisions are made :—

Upper Calcareous Grit, especially developed in the Vale of Pickering about Helmsley and Hackness, 60 feet in thickness, passing up by intercalation into the Kimeridge Clay. It consists of ferruginous marly sandstone with a little cherty limestone, and beds of cement-stone, or 'Throstler.'

Coral Rag, shelly and oolitic limestones, about 60 feet in thickness.[1]

Lower Calcareous Grit, grey marly and cherty sandstones, and sandy clays, 70 to 80 feet, passing downwards into the Oxford Clay. The calcareous grit which forms the main Scar of Filey Brigg belongs to this lower division.

Amongst the fossils of these beds are *Belemnites abbreviatus*, *Ammonites vertebralis*, *Ostrea solitaria*, and *Cidaris florigemma*.

The Coral Rag furnishes a light sandy and brashy arable soil; the pasture is poor and unproductive.

Near Oxford, the Headington Stone (Coral Rag), which consists of 12 feet of Oolitic freestone, has been worked for building purposes. The Coral Rag is also quarried at Wheatley. It is, however, nowhere very durable.

Near Gillingham, where it appears as an oolitic limestone, it has also been worked for building purposes.

UPPER OOLITIC.

KIMERIDGE CLAY.

Oak-tree Clay (Smith).

The Kimeridge clay consists of bluish-grey or yellow unctuous shaly clay, sometimes containing beds of bituminous shale. Crystals of selenite are not uncommon. The clay is sometimes calcareous. It contains nodules of argillaceous limestone or septaria, and sometimes sandy beds and clay ironstone near the base.

The name is taken from Kimeridge, on the coast of the so-called Isle of Purbeck, where the beds of bituminous shale have been used as fuel, and called Kimeridge Coal.

The thickness is about 500 feet near Swindon, but only

[1] The Hildenley limestone belongs to this series.

100 feet near Oxford. Its maximum thickness is perhaps 660 feet.

Amongst the fossils are *Ostrea deltoidea*, *Cardium striatulum*, *Exogyra* (*Gryphæa*) *virgula*, *Trigonia clavellata*, *Rhynchonella inconstans*, *Ammonites biplex*, *A. mutabilis*, and the problematical *Trigonellites*.

Near the junction with the Coral Rag the beds become sandy and the line of demarcation is indistinct.

The Kimeridge Clay occurs in the Vale of Pickering in Yorkshire,[1] in Lincolnshire, Norfolk, Oxfordshire (100 feet), Berkshire, Wiltshire ('North Wilts Clay'), Somersetshire, and Dorsetshire, forming the substratum of the Isle of Portland (600 feet). It is well seen at Gad Cliff and St. Alban's Head, where it is overlaid by the Portland Beds.

In the Sub-Wealden boring the clay was reached at a depth of nearly 300 feet: its thickness appears to be about 660 feet.

The Rev. J. F. Blake has divided the Kimeridge Clay into two sections; the upper of which consists of paper-shales, bituminous shales, and cement-stones, with a maximum thickness of 650 feet or more; and the lower of blue sandy clay with ferruginous concretions called '*doggers*,' having a thickness of from 300 to 500 feet, typically developed in Lincolnshire. But the greatest developments of these sections are *not known in the same area*.

The Kimeridge Clay forms broad vales which are naturally unproductive, the soil being cold and stiff. Most of the land is in meadow or pasture. Oaks grow well upon it. There are no springs.

The decomposition of iron-pyrites has caused 'spontaneous combustion' in places. De la Beche mentions that in Ringstead Bay such combustion, which occurred in 1826, continued for some years.

[1] Portions of the Speeton clay are supposed to represent the Kimeridge clay. See p. 219.

Alum is said to have been formerly made from the shales in the parish of Kimeridge.

Many fruitless trials for coal have been made in this formation, in Oxfordshire, Berkshire, and Dorsetshire.

The bituminous shale has by distillation been used in the manufacture of gas and mineral oils. Bricks and tiles are made in some places.

Near Smedmore, in the parish of Great Kimeridge, is found what the country-people call '*Coal-money*,' generally in barrows on the top of the cliffs, two or three feet below the surface, enclosed between two stones set edgeways and covered with a third, together with the bones of some animal. They are circular, from two to three and a half inches in diameter, and a quarter of an inch thick, on one side flat and plain, on the other convex with mouldings. On the flat side are two, sometimes four, small round holes, perhaps the centre holes by which they were fixed to the turning-press: they are supposed to have been either amulets or money. In support of the latter opinion, it may be observed that 'down with your coal' is in some counties a slang expression for pay your money. There has also been found in the neighbourhood a shallow bowl of Kimeridge coal, six inches high and as many in diameter, containing coal-money.[1]

PORTLAND BEDS.

The Portland Beds, deriving their name from the Isle of Portland, are generally divided into:—

Portland Stone,
Portland Sand.

[1] Conybeare and Phillips. It is considered probable that the Kimeridge coal-money may be simply the refuse from which rings or armlets have been turned.

The Portland Stone consists of white shelly and oolitic limestones, with layers and nodules of chert, attaining a thickness of 60 to 90 feet at Portland, where the beds are largely quarried. The Sands beneath consist of brown and yellow sands, sometimes full of green glauconitic grains, and attain a thickness of about 80 feet. Nodular concretions of calcareo-siliceous grit occur in the sandy beds in Oxfordshire, which from their size and grotesque appearance will attract the notice of every one who ascends Shotover in following the old London road.[1]

Amongst the fossils, many of which occur in the shape of casts, are *Ammonites giganteus*, *Cardium dissimile*, *Lucina Portlandica*, *Trigonia gibbosa*, *T. incurva*, *Perna mytiloides*, *Ostrea expansa*, the 'screw' or *Cerithium Portlandicum*, *Natica elegans*, &c. *Isastræa oblonga* (the Tisbury coral) generally occurs in chert. Remains of *Cetiosaurus*, Fishes, and fragments of wood are sometimes met with.

Portions of the Speeton Clay are considered by Mr. Judd to represent Portland Beds. (See p. 219.)

The beds are developed in Buckinghamshire and Oxfordshire, where the sands have a thickness of 50 to 80 feet. The stone-beds are worked near Aylesbury, Garsington, and Great Haseley. At Haseley the stone is about 8 feet in thickness, and consists of white limestone resting upon grey sandy oolite. The Aylesbury limestone or Pendle stone is a soft calcareous sandstone.

In the Sub-Wealden boring, sandy beds and sandstone, containing chert-nodules, having a thickness of 110 feet, and commencing at a depth of 180 feet, have been classed as Portland Beds.

At Swindon the Portland limestone is about 8 feet in thickness, and the sands below (25 feet thick) contain irregular beds of hard calcareous sandstone.

[1] Conybeare.

It is at Portland, however, that the beds are best studied. The first bed worked for freestone is called *roach*. Its thickness is variable, being in the mean about 15 feet. This is the most valuable bed, and blocks of a vast size are raised from it for the London market. Below the *roach* is the *rubbly bed*, which is not of much commercial value; this is about 5 feet thick, and underneath it is another good bed of freestone, about 6 feet on the average in thickness, called the *whit bed* or *best bed*. This lower bed is worked whenever it is found in convenient situations.

Previously to 1623 this stone does not appear to have attracted any attention. From 1660 it has gradually grown into use. St. Paul's Cathedral, and many of the churches and other large buildings erected in the reign of Queen Anne, were constructed with stone very superior to that now generally employed, as far as regards durability. The quarries whence Sir Christopher Wren obtained the Portland stone which he employed have been long deserted, the only reason assigned being that the merchants find they cannot sell the stone on account of its being a little harder, and thereby more expensive to work.[1]

The stone quarried in the Isle of Purbeck is locally known as 'Purbeck Portland.'

The Chilmark stone, near Salisbury, a siliceous limestone, was used in the construction of Salisbury Cathedral and Wilton Abbey. At Chicksgrove Quarry (near Tisbury), where we find 61 feet of stone, the strata are nearly horizontal, while at Chilmark, Fonthill, and Tisbury the beds are highly inclined.

Some of the softer calcareous beds at Portland are cut into blocks for holystone.

The beds at Portland and Tisbury contain beautiful yellow crystals of sulphate of barytes (sugar candy stone).

[1] Hunt and Rudler.

The soil is a 'poor stone-brash.' Water is held up or thrown out at the base of the Sands by the Kimeridge Clay.

PURBECK BEDS.

This name was given from the great development of the beds in the 'Isle,' or more properly peninsula, of Purbeck.

The formation is essentially of freshwater origin, but it contains a few estuarine or marine beds, which serve, as Edward Forbes considered, to link it with the Oolitic group. It consists of an alternating series of limestones, clays, and marls, attaining a thickness, where best developed, of upwards of 300 feet.

In Dorsetshire three divisions have been made by Mr. Bristow:—

Upper Purbeck Beds,		with Purbeck Marble, 59 feet.
Middle	,, ,,	with Cinder beds (marine), 130 feet.
Lower	,, ,,	with Dirt beds, 140 feet.

The Cinder bed is almost entirely composed of shells of *Ostrea distorta.*

The Dirt beds, of which the greatest is about one foot thick, contain, besides much earthy matter, the fossil trunks and stools of coniferous and cycadeous trees. They mark the old terrestrial soils, and the remains of contemporaneous land-surfaces.

The beds contain fibrous carbonate of lime, termed 'Beef' in the Isle of Purbeck, and 'Horseflesh' in the Isle of Portland. A bed called the Burr stone, a soft limestone, occurs in the upper series of strata; it stands fire, and is used for chimney-work and fire-places.

The fossils include *Paludina carinifera*, *Physa Bristovii*, *Planorbis*, *Limnæa*, *Cyclas*, *Unio*, *Valvata*, *Corbula*, *Cypris*, &c. Hence some beds are termed the Paludina clays, Cypris clays, Unio beds, Corbula beds, &c.

Remains of fishes and crocodiles occur; and chiefly owing to the labours of Mr. S. H. Beckles, remains of marsupial mammalia (insectivorous, predaceous, and herbivorous) have been found. These include *Amphitherium* (or *Thylacotherium*), *Spalacotherium*, and *Plagiaulax*.

Traces of Purbeck Beds occur at Brill in Buckinghamshire, consisting chiefly of argillaceous beds having a thickness of 10 feet. Purbeck Beds, with a thickness of 4 feet, occur at Shotover Hill.

Near Swindon the Purbeck Beds are represented by a hard cream-coloured and bluish marly limestone, with *Paludina*, *Bithynia*, &c. This limestone does not exceed 12 feet in thickness, and has sometimes a botryoidal structure. Mr. Godwin-Austen has pointed out that Purbeck and Portland conditions alternate near the junction of the beds in this locality.

South of Chilmark the Purbeck beds are raised in slabs for tiling. East of Weymouth the beds are highly disturbed and contorted.

From the upper beds of this group is obtained a compact shelly fresh-water limestone known as *Purbeck Marble*. The marble abounds in organic remains of fresh-water snail shells (*Paludinæ*), intermixed with the shells of some minute crustaceans. It occurs in beds which vary in thickness from six to nine inches, and it was much employed formerly in this country for making the slender shafts in Gothic churches; but the introduction of foreign marbles has occasioned its use to be almost discontinued.

It has been worked at Durlestone Bay, near Swanage (Tilly Whim Quarry), Tisbury, &c.

FIG. 16.—*Purbeck and Portland Beds at Tilly Whim, near Swanage.*

[The light-coloured strata in the upper part of the cliff represent the Purbeck Beds; the darker strata below are the Portland Beds.]

In Dorsetshire (Durlestone Bay) the Purbeck Beds contain Gypsum.

In Sussex they occur near Battle, where they consist of shales containing beds of limestone and gypsum. Formerly these beds were erroneously classed with the Hastings and Ashburnham Beds. The total thickness of these Purbeck Beds exposed in Sussex is stated by Mr. Topley to be 330 feet. The lowest beds known are crowded with *Cypridea Valdensis*. *Paludinæ* are rare. The Sub-Wealden boring passed through 180 feet of this formation.

Chapter VIII.

CRETACEOUS.

The Cretaceous system is composed of a system of rocks exhibiting very varied phases, both in their lithological characters and method of formation.

The term would naturally denote a series of rocks characterized by the development of Chalk, but since its first application it has been extended so as to include not only the Chalk, but all the beds to the base of the Wealden, most of which are arenaceous in character.

The divisional line between the Cretaceous and Jurassic systems, like those taken between some other systems, is one of convenience, and not one indicating any great physical break, for the Wealden beds form a connecting link between the two. The Purbeck Beds mark the commencement of those freshwater and estuarine conditions which attended the deposit of the Wealden sediments; and the two groups of strata have sometimes been classed together. Where observed in conjunction, there is no indication of unconformability between them; and, in fact, certain strata in Sussex, considered at one time to belong to the Hastings Sand, have very recently been demonstrated to be Purbeck.

The term 'Neocomian,' first employed in Switzerland to indicate certain strata developed near Neuchâtel, is gradually coming into use in England to embrace both the Wealden and Lower Greensand Strata. The term 'Lower Greensand' originated (as Mr. Judd has pointed out) in the notion that

the beds immediately above and below the Gault were intimately connected, and although the deposits on the Blackdown Hills in Devonshire might warrant a general use of the term 'Greensand,' in other parts of England the distinction between the beds of Upper and Lower Greensand is greater than the terms would seem to imply.

The conditions indicated in the Cretaceous series, looked at in a large way, are (1) Freshwater (Wealden Beds); (2) Fluvio-marine (Punfield Beds); (3) Marine, shallow and moderately deep water (Greensand and Gault), deep sea (Chalk). These deposits, so far as our country is concerned, were successively spread over larger areas, the Upper Cretaceous beds overlapping the denuded outcrops of the Oolitic series, and extending in Devonshire across the Lias and Poikilitic strata.

Therefore, although locally we have indications of transition from the Portland and Purbeck beds to the Wealden deposits, and thence upwards through the Punfield Beds and Greensand to the Chalk, certain portions of our area during Lower Cretaceous times did not receive sediments, but were disturbed and denuded prior to the deposition of the Chalk and other beds upon them.[1]

The Chalk itself, judging from its method of formation, its general purity and organic structure, may probably have extended at one time over the greater part of England, and perhaps the whole of Wales.

[1] There is, however, a palæontological break between the Gault and Lower Greensand.

LOWER CRETACEOUS OR NEOCOMIAN.

WEALDEN.

The Wealden beds are developed over a considerable part of Surrey, Sussex, and Kent, between Haslemere, Hythe, and Pevensey; they are also found in Dorsetshire and the Isle of Wight, and freshwater strata representing them occur at the base of the Lower Greensand near Oxford.

Two great divisions are made in them, the upper or Weald Clay, and the lower or Hastings Beds, having a united thickness of about 1,500 feet.

They constitute a series which represents the Lower and Middle Neocomian.

The Wealden area, as understood by geologists, embraces all the rocks bounded by the Chalk escarpment of the North and South Downs; but the Wealden rocks proper constitute the old district of the Weald, and with these we have now principally to deal.[1]

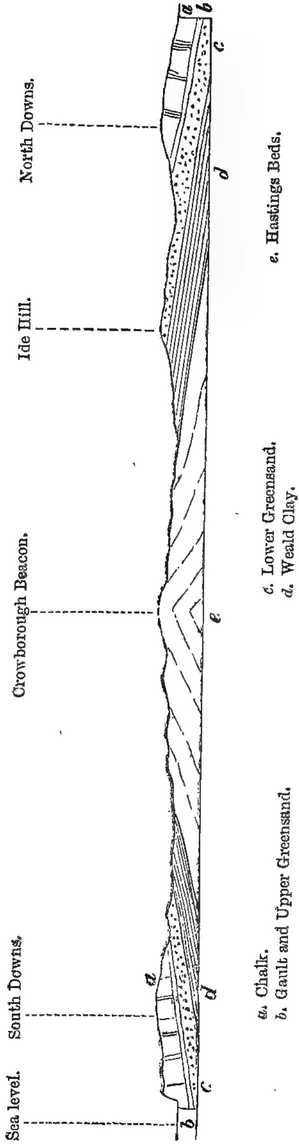
These rocks comprise a series of clays, loose sands, sandstones, and shelly limestones, indicating by their fossils that they were accumulated in an estuary or lake, where freshwater conditions prevailed.

The Wealden and Purbeck beds, indeed, represent the delta and lagoon deposits of an immense river, which in size may have rivalled the Ganges or the Mississippi. (Ramsay.)

[1] For the information concerning the Wealden area I am largely indebted to the Geological Survey Memoir by Mr. Topley.

FIG. 17.—*General section across the Wealden district.*

[Faults and minor anticlinals omitted.]



HASTINGS BEDS.

The lower portion of the Wealden Beds consists for the most part of sands, with subordinate beds of clay; they are well shown in the cliffs at Hastings, and hence the name. The various members of the series are very variable in thickness, and at the same time there is great similarity in the clays and sands that occur at different horizons in it. It is hardly possible to regard the divisions as marking changes that occurred uniformly over the area, and although it is convenient to make lithological divisions, yet the correlation of these in different parts of the district must always be open to doubt as regards contemporaneity. Indeed, in the lowermost division it is now determined that the Fairlight Clays are represented in other localities by sandy beds belonging to the Ashdown Series. Mr. Topley has well observed that such divisions can only be made out, and their relations determined, by actual mapping. In Dorsetshire representatives of the Hastings Sand have been identified at Ridgeway and Lulworth Cove, resting conformably upon the Purbeck Beds.

Ashdown Sand.

Worth Sandstone at Hastings (Mantell).
Ashburnham Beds (Mantell, in part).

This formation consists of sand and soft buff or white sandstone, with bands of loam, blue clay and lignite, having a total thickness of 400 or 500 feet.

In the upper part, near Hastings, there are sometimes beds of calcareous sandstone (Tilgate Stone); also quartzose conglomerate.

In the neighbourhood of Hastings and Fairlight, clays, frequently mottled, predominate in the lower part. These clays were formerly termed the Ashburnham Beds; they are

now called Fairlight Clays by the Geological Survey, and they represent the lower part of the Ashdown Sand as it appears further west. They attain a thickness of 360 feet, the bottom not being seen; the sands above, to which the term Ashdown Sand is restricted, are here about 150 feet thick. The sands are often false-bedded.

The term 'Ashdown Sands' was proposed by Mr. F. Drew, on account of their great development (400 feet) in Ashdown Forest. They form very high ground, as at Crowborough Beacon, and are spread over a large area.

The sands are well developed at Heathfield, and in the cliffs at Hastings; to the east they are underlaid by the clayey modification called the Fairlight Clays, which, beyond Fairlight Glen (where mottled clays increase in quantity), give the colour to the cliffs. The thickness of the sand on the east of Hastings is about 150 feet, while northwards, near Tunbridge Wells, it is about 100 feet.

The Ashdown Sand yields *Endogenites erosa*, which chiefly occurs in a bed of shale not far from the top of the formation. The 'Crowborough Stone' is dug in places on Ashdown Forest.

Wadhurst Clay.

ASHBURNHAM BEDS (of Mantell) in part.

This deposit was named by Mr. F. Drew from the village of Wadhurst, south-east of Tunbridge Wells.

It consists of clay and shale, with a bed of sand towards the base; it also contains, near the bottom, lignite and nodules and bands of clay-ironstone, which (according to Mr. Topley) furnished the chief supply of iron-ore to the old furnaces of the Weald.

The beds sometimes contain calcareous sandstone—the Tilgate Stone of Dr. Mantell[1]—which Mr. C. Gould has noticed

[1] As will be seen by reference to other divisions of the Hastings Sand

at irregular intervals throughout the series, either in large detached rounded masses or in continuous layers. When unweathered and freshly broken it is of a bluish colour; occasionally it passes into a conglomerate.

Sections may be seen in the cliffs on either side of Ecclesbourne Glen, on Telham Hill, south-east of Battle, &c.

The thickness of the deposit at Pembury is about 160 feet, and near Goudhurst about 180 feet; at Rye and Fairlight it is about 120 feet.

This formation is rich in fossil plants, freshwater molluscs, *Hybodus*, *Lepidotus Mantelli*, Crocodiles, Iguanodon, &c. The Tilgate Stone is noted for its reptilian remains: it becomes a regular bone-bed in places. Mr. Topley informs me that the only fossiliferous band which can be considered at all characteristic of any horizon in the Hastings Beds occurs near the base of the Wadhurst Clay. It is composed mainly of shells of a small *Cyrena*, and varies from one to four inches in thickness. Generally there is only one band, but occasionally there are two or even three.

The stone has been much quarried for road-material. The 'Hastings granite' is a local variety of Tilgate stone belonging to the Wadhurst clay. At Beech Green, near Penshurst, it is called Beech Green stone. The shale has been largely dug for 'marl.'

Tunbridge Wells Sand.

HORSTED SAND (Mantell).
= Tunbridge Wells Sand generally (Drew).
WORTH SANDSTONE (Mantell, in part).
TILGATE BEDS (Mantell, in part).

The term 'Tunbridge Wells Sand' was first suggested by Mr. F. Drew, because the beds are well developed in the

series, the 'Tilgate stone' of Dr. Mantell occurs at different horizons in different localities.

neighbourhood of that town, and hard sandstones belonging to the series form the 'High Rocks.'

Mr. Topley states that these rocks much resemble the Ashdown Sand. They consist of loose sand, rock-sand, and loam of a yellowish or white colour.

In the neighbourhood of Hastings they consist of soft yellow and white sand, hard ferruginous sandstone, and shale, having a thickness of 140 or 150 feet.

The beds are exposed at Little Horsted. In the neighbourhood of Tunbridge Wells their total thickness is about 180 feet.

They contain *Lepidotus Fittoni*, *Unio*, *Cyrena*, *Paludina*, *Cypridea*, &c.

Some hard beds of ferruginous sandstone are dug for road-metal.

Grinstead Clay.—The Tunbridge Wells Sands in the western part of the Wealden district are divided into an Upper and Lower Series, by a band of clay which has been mapped by the Geological Survey under the name of Grinstead Clay. The name was suggested by Mr. Drew, because on the north side of East Grinstead the clay occupies a considerable area, and its relations with the Sands beneath may be well seen.

The Grinstead Clay attains a thickness of 50 feet or more in places; at Rye and Fairlight it is only 10 feet in thickness.

It is not quite certain, as Mr. Topley observes, whether this Clay, as mapped on the south side of the Weald, is always on the same horizon. He observes that the clay is generally loamy and nearly always mottled; sometimes it is stiff and shaly. The mottled variety is generally known as 'catsbrains.' There is no positive character, he states, whereby to distinguish it from the Wadhurst Clay. It sometimes occurs only 30 feet above the base of the Sands. It contains *Paludina*, *Cyrena*, &c.

Near Lindfield a bed of conglomerate occurs at the top of the Lower Tunbridge Wells Sand; here Mr. Topley found a fragment of an *Ammonite*, and he would infer that although the pebbles are apparently mostly derived from Palæozoic rocks, yet the Wealden rocks were also partly derived from the waste of Secondary strata.[1]

In the neighbourhood of Cuckfield the Upper Tunbridge Wells Sand contains a bed of clay called the Cuckfield Clay, about 15 feet in thickness, which is described by Mr. Bristow as a somewhat sandy and mottled clay, but is sometimes stiff and shaly.

In this district the beds occur as follows:—

		Feet
Upper Tunbridge Wells Sand.	Sand and sandstone with layers of Tilgate stone at the top	115
	Cuckfield Clay	15
	Sand and Sandstone	70
Grinstead Clay		80
Lower Tunbridge Wells Sand		100

It was from the Cuckfield district, generally spoken of as Tilgate Forest, that Dr. Mantell obtained most of his Saurian remains—*Iguanodon* and *Hylæosaurus*. The larger number were obtained from the quarry at Whiteman's Green, north of Cuckfield. William Smith also collected many reptilian bones from this quarry.

The bones often occur in a rolled state in a conglomeratic band, interstratified with beds of sandstone and calciferous grit (Tilgate stone).

[1] Mr. H. Willett has recently found a nodule containing fragments of an Ammonite at Brede, near Hastings: this occurred in a conglomerate at the top of the Ashdown Sand.

WEALD CLAY.

WEALD MEASURES (J. Middleton, 1812).
OAK-TREE CLAY[1] (W. Smith).

The term 'Weald Clay' was first proposed by Conybeare. The beds consist for the most part of clay or shale, generally brown or blue, containing in places layers of shelly limestone, and sometimes sand, sandstone, and nodules of clay-ironstone and iron-pyrites.

The limestones are composed almost entirely of *Paludina* of several species, large and small; they are called Sussex Marbles.

The lowest bed of marble is seen near Biddenden, Staplehurst, and Crowhurst; another kind, with *P. Sussexiensis*, has been worked near Chiddingfold; while still higher in the series is the most constant bed, containing *P. fluviorum*, known as Petworth and Bethersden Marbles, and Laughton Stone.

The maximum thickness of the Weald Clay has been estimated at 1,000 feet, in the neighbourhood of Leith Hill.

Mr. Topley states that extremely few junction-sections are seen with the Atherfield Clay above; and they are not at all frequent with the Tunbridge Wells Sand below.

In the Isle of Wight, beds identified with the Weald Clay occur between Cowleaze Chine and Compton Bay. The upper portions consist of dark grey shaly clay;[2] the lower of variegated marls, clays, and sandstones. Similar beds also occur at Sandown, while in Dorsetshire representatives are found resting upon rocks which have been identified with the Hastings Sand, and overlaid by Punfield Beds. The total

[1] This term was also used by Smith for the Kimeridge Clay.
[2] These are now included in his Punfield formation by Mr. Judd.

thickness of the variegated Wealden clays and sands is recorded by Mr. Mansel-Pleydell as about 1,800 feet at Swanage, 660 at Mewps Bay, 462 at Lulworth Cove, and 172 feet at Man of War Cove, showing in a very remarkable manner the attenuation of the beds which takes place towards the west.

The Weald Clay yields *Ostrea distorta*, *Melanopsis*, *Cyrena*, *Cypridea Valdensis*, *Corbula*, *Paludina fluviorum*, *P. Sussexiensis*, and fish-remains; it indicates (in the upper part only) fluvio-marine conditions.

The Weald Clay forms wet and rather poor land: most of it is in pasture. It was in former times extensively covered with forests. It has been very much dug as 'marl,' and its ironstone has been largely smelted, particularly in the western part of its area. Calcareous grit occurs in places, often as lenticular masses in the clay; this and the limestone beds were formerly much dug for mending roads, and still are to some extent; they have also been used for building-purposes. Some of the beds are used for brick and tile-making.

Horsham Stone.—About 120 feet above the base of the Weald Clay is a bed of calcareous sandstone capable of being split into slabs, which are used for building, paving, and roofing. Associated with it are beds of sand and sandstone not calcareous, and there is always some interbedded clay. The stone is often strongly ripple-marked, and contains footprints of *Iguanodon*. (Topley.) It has been worked near Itchingfield, West Grinstead, &c.

PUNFIELD BEDS.

Mr. J. W. Judd first suggested that this distinctive name should be applied to the beds which occur between the

Wealden and Upper Neocomian beds in Dorsetshire and the Isle of Wight.[1]

The beds consist of an alternation of yellow sands and clays, with some limestones and marls.

In the Isle of Wight Mr. Judd has made two groups:—

2. Cowleaze series, chiefly clays.
1. Barnes series, false-bedded yellow sands.

They attain a maximum thickness of 230 feet at Atherfield.

Their fauna is brackish or fluvio-marine, including *Ammonites Deshayesii*, *Ostrea*, *Corbula*, *Mytilus*, &c., which indicate conditions differing from the marine Upper Neocomian above, and from the freshwater Wealden below.

Mr. Judd considers that the Punfield beds are represented at Hythe.

SPEETON CLAY (partly Oolitic).

UPPER SHALE (Young and Bird, 1822).

The Speeton Clay, so named by Prof. Phillips in 1829, consists of a series of black and dark-blue clays, sometimes bituminous, pyritic, or slaty, and attains a thickness considerably over 500 feet.

Much discussion has arisen as to the exact equivalents of these clay beds; as the fossils contained in them include species considered to be characteristic both of the Gault and of the Kimeridge Clay.

Mr. J. W. Judd has studied the beds in great detail, and his observations have made it clear that the following formations are represented in the Speeton Clay:—

[1] Punfield is situated on the north of Swanage Bay.

Upper Neocomian. 150 feet.[1]	Black and dark-blue clays. Cement-beds, 30 feet. Light-blue clay containing regular layers of large septaria.
Middle Neocomian.[2] 150 feet.	Dark-blue clays, 80 feet, with a few septaria. Zone of *Pecten cinctus*, 40 feet, dark-blue clays. (Shrimp-bed in lower part: nodules containing *Meyeria ornata.*) Ancyloceras-beds, 30 feet, dark-blue clay with layers of septaria.
Lower Neocomian. 200 feet.	Clays. Zone of *Ammonites Speetonensis*, 100 feet. Clays. Zone of *Am. Noricus*, 50 feet. Pyritic clays. Zone of *Am. Astierianus.*
Portland Beds.	Coprolite-bed. Phosphatic nodules and saurian remains. Fish-bed. Clays and hard dark-coloured rock-bands.
Upper Kimeridge.	Laminated bituminous clays and slaty beds.
Middle Kimeridge.	Light-blue sandy and dark-blue pyritic clays.
Lower Kimeridge.	Dark-coloured clays.

The section of Speeton Clay occurs on the coast to the north of Flamborough Head.

The beds are overlaid unconformably by the Chalk and Hunstanton limestone, and they rest on the Coral Rag, which is exposed at Filey Brigg.

The range of cliffs in which the beds are exposed is much tumbled and obscured by slips; moreover the strata are themselves much disturbed and contorted.

Among the fossils recorded by Mr. Judd are the following:—*Belemnites jaculum*, *Ammonites Deshayesii*, *Rostellaria Parkinsoni*, *Pecten orbicularis* (Upper Neocomian); *Belemnites jaculum*, *Ancyloceras Duvalii*, *Exogyra sinuata*, *Pecten cinctus* (Middle Neocomian); *Belemnites lateralis*, *Ammonites Speetonensis* (Lower Neocomian); *Ammonites rotundus*, *Lucina Portlandica* (Portland Beds); and *Belem-*

[1] No portion of the formation appears to be referable to the Gault. (Judd.)

[2] Equivalent to the Tealby series of Lincolnshire. (Judd.)

nites nitidus, *Exogyra virgula*, *Lingula ovalis* (Kimeridge Clay).

The Septaria are used in the manufacture of Roman cement; upwards of 1,000 tons being annually sent to Hull. Some of the light-coloured clays in which the cement-stones occur produce a fine quality of Portland cement. The Coprolite-bed is worked also.

TEALBY SERIES.

At the base of the Lincolnshire Wolds, beneath the Hunstanton Limestone series, which rests unconformably upon them, there occur certain beds which have been thus divided by Mr. Judd:—

Upper Ferruginous Sands, non-fossiliferous, about 20 feet in thickness.
Tealby series, consisting of alternate beds of sandy clay and limestone, 'greystone,' with many fossils, 40 to 50 feet in thickness.
Lower Sand and Sandstone, with few fossils, 30 to 40 feet in thickness.

The Tealby series yields *Pecten cinctus* (9 to 12 inches in diameter), *P. orbicularis*, *Exogyra sinuata*, *Ostrea frons*, *Belemnites semicanaliculatus*, *Rhynchonella parvirostris*, &c.

The Lower Sand and Sandstone yields a few imperfect fossils. The coarse sandstone of the series has been used for building-purposes, but is by no means durable.

Mr. Judd is inclined to refer the Tealby series to the Middle Neocomian; the fossils of the sandy beds furnish no clue to their probable palæontological equivalents.

The lower beds are underlaid, according to Mr. Judd, by slaty and shaly beds, which constitute 'the upper member

of that great mass of blue clays which in this county represents the whole of the Upper and Middle Jurassic formations.'

LOWER GREENSAND, OR UPPER NEOCOMIAN.

Mr. Godwin-Austen was the first to identify the base of the Lower Greensand with the Neocomian beds of the Continent; and as the term Lower Greensand has been considered to be misleading, it is proposed by many geologists to use the name of Upper Neocomian for these strata.

The beds show the incoming of marine conditions, and they rest conformably upon the great fresh-water deposit of the Wealden formation. The change, however, was not abrupt, as the higher beds of the older formation point to the influx of the sea, and yet indicate no great alteration in the nature of the sediment. 'To explain this, we may suppose that, while the delta of a great river was tranquilly subsiding, so as to allow the sea to encroach upon the space previously occupied by fresh water, the river still continued to carry down the same sediment into the sea.' (Lyell.)

In Surrey, Kent, Sussex, and part of Hampshire the beds are divided by the Geological Survey thus:—

4. Folkestone Beds.
3. Sandgate Beds.
2. Hythe Beds.
1. Atherfield Clay.

In the Isle of Wight and other parts of England these subdivisions have not been made.

The fossils of the series include the following:—*Nautilus plicatus*, *Ammonites Deshayesii*, *Ancyloceras* (*Scaphites*) *gigas*, *Diceras Lonsdalei*, *Trigonia caudata*, *Gervillia anceps*, *Perna Mulleti*, *Terebratula sella*, &c.

Atherfield Clay.

This name was given by Dr. Fitton to the strata shown at Atherfield in the Isle of Wight, which overlie the Wealden and Punfield Beds. (See p. 219.)

The formation consists essentially of clay, with, in places, calcareous bands. In thickness it varies from 60 feet at Godalming to 20 feet at Folkestone.

It has not been determined by the Geological Survey in the eastern part of Sussex, but it has been observed at Petersfield and Pulborough.

The beds display the incoming of marine conditions, for they contain *Panopæa*, *Exogyra sinuata*, *Astarte*, *Arca*, *Perna Mulleti*, &c.

Phosphatic nodules occur in the Atherfield Clay at Stopham, near Pulborough.

Hythe Beds.

This term was proposed by Mr. Drew in 1861.

The beds consist of limestones, sandstones, and sands, with iron-sandstone and chert. The limestone according to Mr. Drew has a greyish-blue colour, and contains fine grains of quartz. It is known as 'rag' (Kentish Rag).

The sandy beds are known as 'hassock' or 'calkstone.'

The thickness of the Hythe Beds is at Maidstone about 80 feet, at Sevenoaks 160 feet, at Nutfield 180 feet, and in the Hindhead district probably as much as 300 feet.

At Sevenoaks there is a bed of chert called the Sevenoaks Stone, which is much used for road-mending.

To the south-west of Dorking the beds contain more sandstone, and in the higher part of the series there is a calcareous sandstone or grit known as Bargate Stone. (Topley.) This stone occurs near Wotton, and is largely quarried near Godalming. (See foot-note, p. 225.)

The Hassock contains *Exogyra*, *Trigonia*, *Iguanodon*, &c.

Phosphatic nodules occur in the Hythe Beds near Godalming.

The Kentish rag is used for building purposes, and sometimes also the Hassock. The rag is quarried near Godstone, Maidstone, Folkestone, &c. It is also burnt for lime, and according to Mr. Bensted in the same way as chalk, more fuel, however, being required.

Fuller's Earth occurs in places; it has been dug at Tillington. Chert (locally called 'whinstone') has been dug near Petworth.

The soil in many places is particularly adapted to the growth of Hops.

Sandgate Beds.

This term was proposed by Mr. Drew in 1861, from the development of the beds at Sandgate, near Folkestone.

They consist of dark clayey sand and clay; the dark colour is due to green particles of glauconite (hydrous silicate of iron, potash and alumina).

At the junction with the Hythe beds there is occasionally a band of phosphatic nodules and pebbles, with fossils in fragments or casts, and bored wood. (Topley.)

These beds are not persistent over the Wealden Area.

The Fuller's Earth of the Lower Greensand is placed in this series by the Geological Survey.

The typical district of the fuller's earth is near Nutfield. Here, it is true, the beds do not resemble the Sandgate Beds of the coast, a circumstance which has led to some doubt as to their exact position in the series. Mr. Topley, however, states that they are upon the same horizon as the fuller's earth of Maidstone, and this has been traced continuously eastwards into the typical Sandgate Beds of East Kent.

The Sandgate Beds are not represented at Godalming:[1] at Folkestone they are represented by a sandy clay about 80 feet in thickness.

At Pulborough they attain 100 feet, as sand and shale; and at Petersfield they are represented by about 75 feet of sand capped by dark sandy clay.

Folkestone Beds.

FERRUGINOUS SANDS (Martin, 1829).

This term was proposed by Mr. Drew in 1861, because the beds are well exposed near Folkestone.

They consist of sand generally false-bedded and 'Carstone,' having an average thickness of 100 feet. At Godalming the thickness is given as 160 feet by Mr. Topley; at Folkestone as 90 feet; at Petersfield 100 feet; and at Eastbourne at about 70 feet.

The term Carstone is applied to a ferruginous grit of irregular nature, which is largely quarried for road metal at Pulborough, Fittleworth, &c. At Ightham hard green grit is found in large masses on the Common, and called the Ightham Stone.

The Folkestone beds form a very persistent stratum beneath the Gault in the Wealden district.

According to Mr. Drew they are well seen in the cliffs east and west of Folkestone, where they consist of light-

[1] Mr. Meyer, in a paper published by the Geologists' Association in 1869, has described the Lower Greensand of the neighbourhood of Godalming in some detail. His classification differs somewhat from that adopted by the Geological Survey, inasmuch as he places the Bargate Stone and the underlying pebbly beds with the Folkestone Beds, and he regards part of the lower strata (here spoken of as Hythe Beds) as Sandgate Beds.

coloured sands, sometimes very coarse, enclosing layers of siliceous limestone (Folkestone Stone) and chert.

The beds contain *Arca*, *Lima*, *Ostrea*, *Lucina*, *Panopæa*, *Pecten*, *Terebratula*, &c.; also *Exogyra sinuata*, *Ammonites Deshayesii*, and *Ichthyosaurus campylodon*.

Sometimes phosphatic nodules occur in the upper part of the series, at the junction with the Gault: they have been worked at Farnham.

Glass-sand is often dug from the Folkestone Beds; large quantities are obtained for this purpose at Reigate (Reigate Sand), and also in Kent at Aylesford, Berstead, Hollingbourn, and elsewhere. (Topley.)

Beyond the Wealden district, as before mentioned, the Lower Greensand has not been mapped out into separate divisions.

In the Isle of Wight the beds (called Shanklin Sand) attain a thickness of from 800 to 900 feet: they have been thus divided:—

	Feet
Upper series, composed of variously coloured sands, with ironstone and cherty concretions . . .	250
Middle series, consisting of green and grey sands, with beds of calcareous sandstone and cherty limestone .	400 to 500
Lower series or Atherfield Beds, consisting of clays with subordinate beds of sandstone	150

The following palæontological divisions were also made by Dr. Fitton:—

	Feet	ins.
Various sands and clays	118	4
Upper clays and Sand-rock	118	0
Ferruginous sands of Blackgang Chine	20	6
Sands of Walpen and Blackgang Undercliff	97	0
Foliated clay and sand	25	0
Cliff-end sands	20	0
Upper Gryphæa (Exogyra) group	16	0
Walpen and Ladder Sands	42	0
Upper Crioceras group	46	2
Walpen clays and sands	57	0
Lower Crioceras group	16	3
Scaphites group	50	4
Lower Gryphæa (Exogyra) group	32	0
The 'Crackers'[1]	85	0
Atherfield Clay	60	0
Perna Mulleti Bed	5	3
	808	10

In Dorsetshire,[2] Devonshire, and Somersetshire the Lower Greensand has not been identified; but it may perhaps be partly represented by some of the sandy beds in the Blackdown series. (See p. 236.)

In Wiltshire ferruginous beds which are paralleled with the Hythe and Folkestone beds contain *Diceras Lonsdalii.* The whole series has a thickness of from 25 to 30 feet. It consists of red, yellow, and grey sands containing, according to Lonsdale, the following beds in descending order:—

Calcareous grit with sandy clay.
Sandstone.
Quartzose conglomerate.
Ironstone-nodules.
Chert (comparatively rare).

At Seend, where the beds rest on the Kimeridge Clay,

[1] This bed contains two layers of ferruginous sandy nodules, called Crackers, from the noise produced by the waves in dashing over the ledges formed by them on the shore. (H. W. Bristow.)

[2] Dr. Fitton considered that the Lower Greensand might be represented on the east side of Lulworth Cove.

they comprise sands and irony-sandstones with a bed of quartzose sand at base. Some of the iron-ore is very rich, and it is now largely worked.

Near Swindon the Lower Greensand consists of red or yellow ferruginous sand or gravel, composed, according to Mr. Hull, of pebbles of quartz, lydian stone, slate, and oolite.

Near Farringdon are the celebrated 'Sponge-Gravel' Beds of Coxwell. The 'Sponge-Gravel' crops out over a space of about a mile by a quarter of a mile, and is from 25 to 40 feet thick, forming a plateau based on Kimeridge Clay, and capped in places by dark ironsand. The bed is a conglomerate of sand and fossils, mostly hardened by a ferruginous cement. There has been much dispute as to the age of this gravel, which has been variously referred to the Lower Greensand, Upper Greensand, and the highest (Maestricht) Chalk.

It is now allowed that these gravels belong to the Lower Greensand, on these grounds:—1. Similarity with Lower Greensand at Seend, &c.; 2. Presence of Lower Greensand Brachiopoda and Echinodermata; 3. Infraposition to the Lower Greensand ironsand of Furze Hill; 4. Dissimilarity to Upper Greensand, which is fairly developed in the neighbourhood.

The fossils are of two sorts—those that lived on the spot, and those derived from Oolitic beds.[1] The latter can be distinguished by colour and condition, and they are chiefly the remains of Vertebrates; the former are Sponges, Polyzoa, Echinoderms, and bivalve Mollusca, the absence of univalves being remarkable. The Sponges (*Manon*, *Verticillopora*, &c.) are most important, both as forming a large part of the gravel and from their good preservation.

[1] Mostly from Kimeridge Clay and Coral Rag.

'Cole's Pits' are old excavations, extending over 14 acres. They have, by some, been regarded as the remains of early British habitations; and the largest has been assigned to no less a person than 'King Cole.' The pits are only the remains of old workings.[1]

Overlying the gravel beds are a series of clays and sands with ironstone-bands. The thickness of the entire deposit has been estimated at from 70 to 100 feet.

Hard beds near Farringdon have been made into mill-stones.

At Shotover Hill, near Oxford, there are certain beds which have been referred to the Wealden series, but are now usually recognized as Lower Greensand. They consist of fine-grained variegated sands with white clay and ochre, and in the upper part contain irregular masses of siliceous iron-ore; the thickness is about 80 feet, according to Prof. Phillips. They contain *Unio*, *Cyrena*, *Paludina*; also Coniferous wood. They rest upon the Purbeck and Portland Beds, and seem to be connected with the sands, ochres, and fuller's earth of Woburn.

Near Aylesbury there is a brown and white sand about 8 feet in thickness, which at Hartwell has been used for glass-making.

Near Fenny Stratford the thickness of the sands is given as 250 feet by the Rev. T. G. Bonney; while near Ampthill it is but 25 feet. Near Potton he considers that the series must be over 100 feet in thickness.

Near Woburn, Leighton, Ampthill, Sandy, Wicken, Potton, and Upware the iron-sands contain near their base a variable band of gravel or nodule-bed (6 in. to 2 feet in thickness) full of fossils, mostly water worn, including many saurian

[1] These notes are taken from an abstract of a paper by Mr. E. C. Davey, published in the *Geological Record*, vol. i., p. 8.

and fish remains and 'coprolites.' Most of the fossils are derived from the Wealden, Purbeck and Portland Beds, Kimeridge Clay, Coral Rag, and Oxford Clay. Some indigenous fossils are found, and they indicate that the beds are of the age of the Lower Greensand.

Mr. Bonney observes that the 'coprolites' consist of wood, mineralized by phosphate, casts of molluscs, bones, and shapeless lumps. They are worked for manure.[1]

Fuller's Earth has been dug at Wavendon, near Woburn, where the beds have a thickness of from 150 to 200 feet.[2]

Beneath London, from the records of the deep well at Kentish Town, Mr. Prestwich has estimated the thickness of the Lower Greensand at 188 feet. The beds consist of alternations of sands, sandstones, and clays, mostly red.

The Lower Greensand occurs at Ely, resting on the Kimeridge Clay: it is here about 8 or 9 feet in thickness. At Haddenham, where it is 15 feet in thickness, it consists of light brown ferruginous sand, and is a water-bearing stratum. It contains fragments of wood and some obscure shells.

The Lower Greensand of Norfolk consists of alternating beds of red and white sand and sandstone about 70 feet in thickness.[3] Some of the beds, as in the cliff at Hunstanton, are conglomeratic, containing quartz pebbles.

The hard beds, locally termed Carstone (or Quern stone), are worked for building-purposes, while the white sand is used in the manufacture of glass. The beds rest upon the Kimeridge Clay. In one place they contain a seam of fuller's earth.

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[1] For details, see Teall, *On the Potton and Wicken Deposits.*

[2] These beds are the Woburn Sands or 'Sand of Bedfordshire.'

[3] Near Snettisham the thickness is estimated at 100 feet.

UPPER CRETACEOUS.

GAULT.

BLUE MARL (of Folkestone, &c.).
GALT OR GOLT.

The Gault may be described as a stiff blue clay, sometimes calcareous and micaceous, and now and then containing indurated nodules and small septaria. Nodules and crystals of iron-pyrites are abundant, and many of the fossils are pyritic. A layer of Iron grit occurs at its base in parts of Sussex; but in this position there is generally found in the Wealden district, and also at Upware, a band of Phosphatic nodules.

The average thickness of the Gault is 100 feet; at Folkestone it is 100 feet, and at Maidstone 150 feet.

It may be well studied at Copt Point and Eastwear Bay near Folkestone.

Mr. Topley observes that between the Gault and the uppermost division of the Upper Neocomian or Lower Greensand—the Folkestone Beds—there is in the Wealden district a great palæontological break, and there is a partial break in other parts of England: nevertheless, in no locality is there any evidence of unconformability in the strata, and there is generally a lithological passage from one formation to the other.

The Gault overlaps the Lower Greensand in places.

The common fossils of the Gault are:—*Ammonites splendens*, *Hamites* (*Ancyloceras*) *spiniger*, *Belemnites minimus*, *Rostellaria carinata*, *Dentalium ellipticum*, *Inoceramus sulcatus*, *Plicatula pectinoides*, &c.

The Gault forms what may be termed an unproductive soil, but it is well adapted for pasture. It is sometimes

called 'black land.' The beds are frequently used in the manufacture of bricks and tiles.

The Gault of Folkestone has always been a famous collecting-ground; it has been divided into the following zones:[1]—

Upper Gault. (about 72 feet.)	Zone of *Ammonites rostratus*.
	„ „ *Kingena lima*.
	„ „ *Ammonites varicosus* (*Inoceramus sulcatus*).
Junction bed	„ „ „ *cristatus* (Nodule bed).
Lower Gault. (about 28 feet.)	„ „ „ *auritus* (Dark bed).
	„ „ „ *denarius* (Mottled bed).
	„ „ „ *lautus* (Coral bed).
	„ „ „ *De la Ruei*.
	„ „ Crustacea (*Palæocorystes*), (Crab bed).
	„ „ *Ammonites auritus*, var.
	„ „ „ *interruptus*.

In the Isle of Wight (Mr. Bristow observes) the Gault has received the name of the 'blue slipper,' from the tendency of the overlying strata to slip or slide over its surface. It has a thickness of 100 feet in Compton Bay, but passes so insensibly into the Upper Greensand as to be scarcely distinguishable from it.

In Dorsetshire[2] the Gault is well developed at Shaftesbury, but here and on the borders of Somersetshire where it sometimes reposes on the Kimeridge Clay it is difficult, in the absence of fossil evidence, to separate the two formations. The Gault has been traced in places as far as Lyme Regis, where it rests upon the Lias Clays; but it is only a few feet in thickness. (See p. 237.)

In Wiltshire the Gault varies from 80 to 140 feet in thickness; in Oxfordshire and Berkshire it is about 250 feet according to Mr. Hull; and in Buckinghamshire about 130 feet.

[1] See papers by Price, De Rance, and others.

[2] It may be represented at Lulworth Cove.

In Cambridgeshire the Gault appears as a stiff pale bluish-grey clay, 150 feet in thickness; and may be studied in the pits around Barnwell. It occurs near Stoke Ferry in Norfolk, and, according to Mr. C. B. Rose, may be traced as far as Flitcham, beyond which to the coast its place is taken by the Red Chalk.

In a deep well-boring at Norwich the Gault was proved to be 24 feet in thickness; at Harwich it was proved to be about 40 feet; and at Kentish Town, London, to be 130 feet.

Hunstanton Limestone, or Red Chalk.[1]—This formation as developed in the cliff of Hunstanton on the north-west coast of Norfolk rests upon the Lower Greensand (Carstone) and is overlaid by the Chalk. The beds are apparently conformable, but the fossils of the Red Chalk have led geologists who have studied them to refer the rock differently, either to the Upper Greensand or Gault, or to a combination of both. Thus Murchison in 1836 placed the Red Chalk with the Upper Greensand, while Mr. C. B. Rose (1835) and Edward Forbes (about 20 years later) considered it as Gault; Mr. Seeley has referred it to the Upper Greensand, and Mr. Judd inclines to regard it as combining both formations.

The Rev. T. Wiltshire, who has for many years studied the beds, has recently brought forward conclusive evidence for considering the fossils of the Red Chalk as equivalent to those of the upper portion of the typical English Gault.

The deposit is four feet in thickness, and may be divided into three bands, the upper of which has a large quantity of fragments of *Inocerami*, the middle is rich in *Belemnites*, and the lower contains numerous *Terebratulæ*.

The whole series contains numerous rolled fragments of quartz and slate.[2] Amongst the more abundant fossils are

[1] Hunstanton Red Rock. (Seeley.)

[2] From analyses by Mr. David Forbes it appears that the Red Chalk does not contain quite so much iron as does the Gault; so that if

Spongia paradoxica, *Pentacrinus Fittoni*, *Holaster suborbicularis*, *Vermicularia umbonata*, *Terebratula biplicata*, *T. capillata*, *Inoceramus Crispii*, *I. tenuis*, *Ostrea vesicularis*, *Ammonites auritus*, *Belemnites attenuatus*, *B. minimus*, and *B. ultimus*.

Overlying the Red Chalk is a bed of hard white chalk 15 to 18 inches in thickness, containing *Spongia paradoxica*, and called the 'Sponge Bed.' This bed is sometimes included in the Hunstanton Series.

Mr. Judd has traced the Hunstanton Series through Lincolnshire, where it has a thickness of 14 feet and upwards; and at Speeton he has estimated its thickness at 30 feet. In Lincolnshire other beds of Red Chalk occur above the Hunstanton Series.

UPPER GREENSAND. (Murchison.)

FIRESTONE. } Merstham beds.
MALM ROCK. }
CHLORITIC SAND. (Lyell.[1])

The Upper Greensand consists of greenish grey sand and sandstone; the typical green beds generally being charged with Glauconite (hydrous silicate of iron, alumina, and potash).

the latter rock were subjected to any oxidizing influences it would assume the red colour of the Hunstanton rocks, as it does also by burning. The term 'ferruginous,' therefore, as applied to rocks is by no means a necessary indication that they contain any larger proportion of iron than do many rocks that have no ferruginous appearance.

[1] The term Chloritic, used by Lyell, is open to objections on the grounds that the term merely indicates a colour which is far from predominant; and that the green beds are charged with Glauconite (not Chlorite). It was considered by Ehrenberg, and more recently by Carpenter, that the green grains are very frequently internal casts of Foraminifera in Glauconite.

The firestone is a pale calcareous sandstone used for building purposes, for the floors of furnaces, for hearths, &c.; the malm rock has a more chalky appearance. They appear to represent one another. The former is noted by Mr. Topley as occurring at Godalming and Nutfield; the latter at Petersfield, Pulborough, and Hassocks Gate.

The thickness of the Upper Greensand is about 60 feet on the average in the Wealden district. At Petersfield it is 80 feet, at Eastbourne 40 feet, at Godalming 50 feet, and at Nutfield 40 feet.

It is exposed north of Folkestone and at East Wear Bay with a thickness of less than 20 feet.

Between Merstham and Reigate (Reigate Stone) the beds are largely worked. Near Betchworth beds of Hearth stone are worked—this rock is a soft calcareous sandstone.

The Upper Greensand contains *Pecten quinquecostatus*, *P. quadricostatus*, *P. asper*, *Cardium Hillanum*, *Exogyra conica*, *E. columba*, *Ostrea carinata*, *Vermicularia concava*, *Siphonia costata*, and *S. pyriformis*.[1]

In the Isle of Wight the beds, as described by Mr. Bristow, consist in the upper part (for 15 or 20 feet) of calcareous sandstones; these latter rest upon blue chert-beds and sandstone enclosing a layer of freestone four feet in thickness; the lower beds consist of yellowish-grey micaceous sands with sandstone and chert, overlying bluish micaceous sands. The entire series has a thickness of about 150 feet. The higher beds have been quarried on the north side of Shanklin Down, and in other places, for building-stone; while the cherty strata furnish an excellent stone for road-mending.

In Dorsetshire, at White Nore (or White Nose) Cliff, the cherty and sandy beds forming the Upper Greensand have a thickness of about 100 feet.

[1] *Siphonia* is met with particularly in the beds at Warminster and Blackdown.

These rocks are very conspicuous at Golden Cap (Gilten Cup), to which from their colour they give the name. They cap the conspicuous hills of Pillesdon Pen and Lewesdon (called by sailors the 'Cow and Calf'), and extend westwards in outlying masses to Sidmouth and the Haldon Hills in Devonshire.[1] Northwards they form the Blackdown Hills, and in this district the age of the different portions of the series has been much questioned.

De la Beche gave the following divisions of the Greensand near Lyme Regis:—

	Feet
Yellowish-brown sandstone, with chert seams in lower part	70 or 80
Yellowish-brown sand (fox-mould)	70 or 80
Greensand and sandstone containing indurated nodules called 'Cow stones'	40 or 50

The total thickness, however, can scarcely exceed 180 feet.

In the cherty beds *Pecten asper* and *P. quinquecostatus* are abundant, and in the sandy beds below *Exogyra conica* is frequently met with at different horizons.

Blackdown Beds.—On the Blackdown Hills the chert-beds have for the most part been denuded, and the series is represented by the sands containing concretionary beds.

The exact age of the several portions of the Greensand of this district has formed the subject of considerable dispute among Palæontologists. Representatives not only of Upper Greensand, but also of Gault and even Lower Greensand (or Upper Neocomian) have been considered to be present. There is no doubt that the Greensand beds of the district form one conformable series and one physically connected in every sense: the fossils naturally vary according to the

[1] The deposits coloured as Upper Greensand near Newton Abbot are for the most part commingled with gravel-beds containing pebbles and blocks of flint and chert, and I have not seen any traces of undoubted Greensand *in situ*.

varying nature of the deposits, and these indeed exhibit so much change in different places that they cannot with certainty be correlated.

In the Railway-cutting at Wilmington, near Honiton, Mr. Ussher has noticed clayey beds at the base of the Greensand which seem to be referable to the Gault; while at Lyme Regis (Black Ven) Mr. Etheridge has positively identified the Gault, *underlying* the cherty and sandy series, and resting on the Lias.

The Greensand of the neighbourhood of Chard consists in its upper part of Chert-beds, and lower down of sands of varied hue, green, brown, and yellow. The topmost beds of the Greensand consist, however, of one or more layers of calcareous sandstone or grit, which are sometimes burnt for lime, and generally crop out in the roads and lanes and along the scarps of the hills. (See fig. 18.)

The Chert-beds very frequently weather sandy on the exterior—nodules may be found exhibiting only a small internal nucleus of chert. Again sandy concretions or aggregations may be obtained near Honiton, sometimes *in situ*, which exhibit the formation of chert from a centre.

Near Kentisbere and Broadhembury (Blackdown Hills) irregular concretions of sandstone are met with in the lower part of the Greensand series, which have been largely worked for scythe-stones or whetstones, called Devonshire Batts.[1] At Penzlewood (Pen Selwood) similar beds have been worked at the old Pen pits.

Near Widworthy (at the base of the Chalk), according to Dr. Fitton, is a siliceous bed called 'Grizzle' by the quarrymen, about 5 feet in thickness, and containing greenish particles. It has been much used for building-purposes.

In Wiltshire the Upper Greensand has a thickness of from 90 to 140 feet.

[1] Sometimes called Rubber-batts, or Balkers, in Dorsetshire.

It is well shown at Devizes and near Seend; in the upper part it consists of sandstone and chert, and in the lower of light brown and grey sands with green (glauconitic) grains. Near Swindon its thickness is about 60 feet.

The Upper Greensand about Wantage and Wallingford, as described by Mr. Hull, consists of soft dark-green sands (20 or 30 feet in thickness), resting upon whitish siliceo-calcareous strata.

The total thickness at Woolstone is 60 feet, and at Didcot upwards of 100 feet; further east the beds become thinner.

Near Prince's Risborough, Mr. Whitaker describes the Upper Greensand as consisting almost wholly of a soft white crumbling sandstone, sometimes calcareous, overlaid by a thin deposit of clayey greensand. The same authority remarks that in his paper on the Kentish Town well-section, Mr. Prestwich classes with this formation 58 feet 9 inches of bluish-grey marl, rather sandy, and 13 feet 9 inches of dark green sand mixed with grey clay: he would however limit the thickness to 13 feet 9 inches. Mr. Prestwich remarks that the Chalk Marl passes so insensibly into slightly sandy marls representing the Upper Greensand, and these into the Gault, that it is difficult to draw any satisfactory lines of division.

Traced to the north-east the Upper Greensand dies out. In Cambridgeshire the 'coprolitic' beds have been considered to represent the Upper Greensand, but while carrying on the Geological Survey Mr. Whitaker concluded (in 1868) that the nodule bed was really the base of the Chalk Marl, an opinion which has been corroborated by the researches of Mr. Jukes-Browne.

In Norfolk the Upper Greensand may be represented in the 'Sponge bed' at the base of the Chalk. (See p. 234.) In the deep boring at Harwich the thickness of the Greensand was proved to be about 20 feet.

The Upper Greensand is essentially a water-bearing stratum.

CHALK.

The Chalk is one of the best known rocks; it forms some of the marked features in our island, it is developed over a large area, and from its nature is more easily identified than any other formation.

The Chalk may be described as a soft white limestone, for it is almost wholly composed of Carbonate of Lime, and it is characterized in its upper part by nodules and bands of flint. It is remarkably free from sand or pebbles, except in its western extremity near the junction with the Greensand below: it contains many nodules of iron-pyrites, sometimes called 'thunderbolts.'

Chalk (says Prof. Wyville Thomson) consists of a large proportion of fine amorphous particles of lime, with here and there a portion of a Globigerina shell, and more rarely one of these shells entire, and a considerable proportion—in some examples coming up to nearly one-tenth of the whole—of 'coccoliths,' which are indistinguishable from those of the Atlantic ooze.

The following analyses of Chalk were made by Mr. David Forbes:—

	White Chalk, Shoreham, Sussex.	Grey Chalk, Folkestone.
Carbonate of lime	98·40	94·09
„ „ magnesia	0·08	0·31
Insoluble rock débris	1·10	3·61
Phosphoric acid	—	a trace
Alumina and loss	0·42	
Chloride of sodium	—	1·29
Water	—	0·70
	100·00	100·00

The following are the general divisions made in the Chalk :—

Upper Chalk or Chalk-with-Flints.
Lower Chalk or Chalk-without-Flints.
Chalk Marl or Grey Chalk.
Chloritic Marl.

The Upper Chalk is characterized more especially by *Ananchytes ovatus* ('Sugar loaf'), *Galerites albogalerus*, *Micraster cor-anguinum*, *Marsupites ornatus*, *Terebratula carnea*, *T. biplicata*, *Rhynchonella octoplicata*, *Pecten nitidus*, *Lima* (*Spondylus*) *spinosa*, &c.

The Lower Chalk and Chalk Marl contain *Turrilites costatus*, *Baculites anceps*, *Pecten Beaveri*, *Hippurites*, palatal teeth of *Ptychodus decurrens*,[1] &c.

The Chloritic Marl contains many fossils (some similar to those of the Lower Chalk), such as *Ammonites Rothomagensis*, *A. Mantelli*, *Scaphites æqualis*, *Turrilites Wiestii*, *Terebratula biplicata*, and *Ananchytes* (*Holaster*) *subglobosus*. *Ostrea vesicularis*, *Inoceramus Lamarckii*, and *Ventriculites* are generally distributed in the Chalk.

The Chalk has yielded many remains of the Fishes *Otodus*, *Lamna*, *Beryx*; also of the Reptiles *Pterodactylus*, *Mosasaurus*, *Chelone*, &c.

The Chalk is considered to have been formed in a deep and open sea, and indeed the researches which have been carried on in the North Atlantic Ocean show that materials for a continuous bed of limestone, with flint nodules, are now being deposited there. Prof. Huxley, who has described the ooze derived from depths between 1,700 and 2,400 fathoms, considers that 85 per cent. of the whole belong to one species of *Globigerina* (a genus of Foraminifera), 5 per cent. to other calcareous organisms of at most four or five species, and that the remaining 10 per cent. consist partly of granules of

[1] Allied to the *Cestracion* or Port Jackson Shark.

quartz, siliceous spicula of sponges, and partly of animal (*Polycystina*) and vegetable (*Diatomaceæ*) organisms provided with siliceous skeletons and framework. In this ooze or mud the organic bodies were found to be connected by a mass of gelatinous matter (called 'Bathybius' by Prof. Huxley), and associated with the minute bodies termed 'Coccoliths' by him, and those called 'Coccospheres' by Dr. Wallich.[1]

It is remarkable that while the Upper Chalk is almost always associated with flints, the Chalk itself contains but a trace of silica.

The Chalk-mud of the Atlantic on the other hand, as described by Prof. Wyville Thomson, contains not more than 60 per cent. of carbonate of lime, with 20 to 30 per cent. of silica, and varying proportions of alumina, magnesia, and oxide of iron. A considerable portion of this silica is inorganic sand; but much of it consists of siliceous organisms uniformly distributed through the whole mass.[2]

These siliceous particles and organisms possibly give us the clue to the formation of the flints, which consist almost entirely of silex, generally aggregated round some nucleus of sponge, sea-urchin, or mollusc, and, as we now find them, they occur in nodules and bands. The reconstruction, however,

[1] *Coccoliths* are joints of a minute unicellular alga (*Melobesia*) living on the sea-surface and sinking down and mixing with the calcareous ooze. *Coccospheres* are small transparent membranous balls, which, according to Mr. H. J. Carter, are the sporangia of *Melobesia*. Dr. O. Schmidt has also defined the closely allied Rhabdoliths, which abound in some sea-muds. In a large number of limestones of all ages Dr. Gümbel has detected the characteristic 'coccoliths,' and Mr. G. M. Dawson has discovered both Coccoliths and Rhabdoliths in the Chalk of Manitoba, North America.

[2] Sea-water contains a minute percentage of silica, and probably this furnished to the organisms the material for forming their siliceous structures.

of inorganic silica from mineral solutions, may account for these local silicifications.

That the formation of the flints themselves was essentially due to chemical agency there can be no question; but to what particular causes the comparatively regular bands and sometimes tabular layers of flint are to be attributed we are not yet in a position to state.

Prof. Thomson has observed that we often find the moulds and outlines of organisms considered to have been siliceous, from which the whole of the silica has been removed; and cases occur in which a portion of the delicate tracery of a siliceous sponge has been preserved entire in a flint, while the remainder of the vase which projected beyond the outline of the flint appeared in the Chalk as a trellis-work of spaces, vacant or loosely filled with peroxide or carbonate of iron. On the other hand, calcareous organisms have been perfectly replaced by silica in the white powder within some flints, as remarked by Prof. T. Rupert Jones and Mr. Joseph Wright.

The results of deep-sea dredgings have proved that many forms of life there met with are analogous to those of our Chalk.

Prof. T. Rupert Jones has determined that 19 forms of Foraminifera out of 110 from the Atlantic mud are identical with Chalk species.

Amongst the other forms recorded by Prof. Wyville Thomson are Sponges from depths of 400 to 600 fms.; Stony Corals (Madreporaria), 150 to 700 fms.; Crinoids: *Pentacrinus* 100 fms., *Rhizocrinus* 300 to 530 fms., and *Bathycrinus* 2,435 fms., being the greatest depth reached by the dredge. Starfish occur likewise, and among Echinoderms some range to the greatest depth, and the *Cidaridæ* range from 100 to 400 fms. Many genera of Mollusca have been found in deep water; *Fusus* at a depth of 1,207 fms.,

and *Pleurotoma* at 2,090 fms. The *Terebratula striata* of the Chalk is considered very like the *T. caput-serpentis* dredged at depths varying from 70 to 1,200 fathoms.

On physical grounds both Thomson and Carpenter are inclined to believe that a considerable portion of the deep Atlantic area has been continually under water, and that consequently a deposit has been forming there uninterruptedly, from the period of the Chalk to our own; and that our Tertiary beds represent the mineral accumulations and the fauna of the margin of some sea whose deep-sea fauna is unknown, being still beneath the Atlantic.[1]

Chloritic Marl.

The Chloritic Marl is a deposit concerning which very different opinions have been expressed, especially in regard to its classification, whether it should be placed with the Chalk or with the Upper Greensand.

It seems (according to Mr. Topley) that in the Wealden district it is more closely allied to the Greensand, and in Cambridgeshire and in the west of England it seems very clearly to constitute the basement bed of the Chalk. Such being the case it may very naturally be regarded as a passage-bed, but, at the same time, it would obviously be inconvenient to designate it as a separate formation owing to its feeble development; and therefore, looking to the general nature of its organic remains and of its lithological characters, it may best be included with the Chalk, as Edward Forbes originally advocated.

The Chloritic Marl consists of white or pale-yellow marl with dark green glauconitic grains, phosphatic nodules, and nodules of iron-pyrites. Sometimes the bed is indurated. The origin of the phosphatic nodules, often miscalled 'Co-

[1] The great Tertiary marine fauna of the Eastern Nummulitic sea may, however, be regarded as an equivalent.

prolites,' is a subject that has been much discussed. Perhaps the simplest explanation is that given by the Rev. T. G. Bonney; he points out that Phosphate of lime is present in small quantities in the sea, in several rivers, and in numerous mineral springs; it is found in many plant and animal remains; and in the form of Apatite it is met with in many rocks. He considers that the phosphatic nodules are due to concretionary action, and have been formed by segregation out of mud saturated with phosphate of lime. The 'coprolites' in the Chloritic Marl of Cambridge he considers as derived from more extensive deposits of Gault age.

In the Wealden District the Chloritic Marl occurs in the neighbourhood of Alton and Selborne. It contains a good deal of phosphatic matter, and the beds have been largely worked at Froyle. According to Mr. Bristow the thickness of the bed varies from a few inches to 10 or 15 feet.

The celebrated 'coprolite' beds found near Farnham in Surrey, and worked at Dippen Hall, vary in thickness from 2 to 15 feet. This neighbourhood is celebrated for its hop-gardens.

In the Isle of Wight the Chloritic Marl is about 5 feet in thickness, and contains phosphatic nodules.

In Dorsetshire the Chloritic Marl has a thickness of about 18 inches, and contains phosphatic nodules. It is well seen in the neighbourhood of Chard, where it is exceedingly fossiliferous. (See fig. 18.)

In Wiltshire the thickness is sometimes 6 feet. At Wroughton, near Swindon, the phosphatic bed is 18 inches thick.

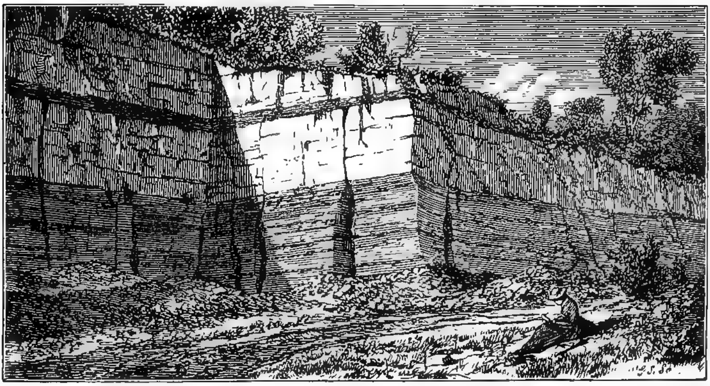
Between Hitchin and Cambridge the 'Coprolite' beds have been largely worked.

The so-called Cambridge Upper Greensand, which consists merely of a bed about a foot in thickness containing Phosphatic nodules and many derived fossils, *Inoceramus*,

Terebratula, &c., is now regarded as belonging to the Chalk.

Mr. Jukes-Browne observes that the 'coprolites,' fossils, and green grains which it contains have been mainly derived from the denudation of the Upper Gault; and he considers the bed to belong to the base of the Chalk Marl, the Upper Greensand being absent. As Mr. Bonney observes, it is probably homotaxeous with the Chloritic Marl.

FIG. 18.—*Section at Snowdown, Chard.*



4. Lower Chalk.
3. Chloritic Marl, 18 inches.
2. Calcareous Sandstone, 7 feet 8 inches. } Upper Greensand.
1. Chert Beds (15 feet shown).

This phosphatic deposit is particularly rich in vertebrate remains, including one Bird of the Ornithosaurian group, many Reptiles, including *Ichthyosaurus*, *Plesiosaurus*, *Chelone*, and the Deinosaurian *Acanthopholis* (also found in the Chalk Marl of Folkestone); likewise many Fish-remains.

Range of the Chalk.

The Chalk extends from Flamborough Head inland, forming the Yorkshire Wolds, and thence running beneath the Humber near Hull to form the Lincolnshire Wolds.

It constitutes the foundation of the greater part of Norfolk and Suffolk, but is in these counties very much concealed by Glacial Drifts, and does not there appear in such conspicuous hills as those which extend from Royston in a south-westerly direction, forming the Royston and Luton Downs, the Chiltern Hills, the Marlborough Downs, and Salisbury Plain. Thence the Chalk stretches out irregularly to the west beyond Dorchester, and is found in outliers near Chard, Seaton, and Sidmouth. Eastwards of Salisbury Plain the Chalk forms a large extent of Hampshire, it is found in the Isle of Wight, and borders the Wealden district, forming the cliffs from Margate to Folkestone on the north, and those from Beachy Head to Brighton and Little Hampton on the south. It is also exposed at Gravesend and Grays Thurrock.

In Yorkshire the following succession of the Chalk strata has been determined by Professor Phillips:—

		Feet
Chalk	Upper Chalk, rich in *Spongiadæ, Marsupites*, &c.	100
	Middle Chalk with flints, and few fossils	400
	Lower Chalk, with few fossils	100
	Red and Grey Chalk, with many fossils	40
Red Chalk, *Belemnites Listeri*, &c.		30

He observes that the unconformability of the Chalk to all the strata beneath it is a striking feature of the geology of Yorkshire. The lowest bed of Red Chalk is the equivalent of the Hunstanton Limestone.

Mr. Judd has pointed out in regard to the Chalk of Lincolnshire, that the occurrence of the flint layers is very irregular. Above the Chalk Marl is a considerable thickness of hard Chalk (as in Norfolk) which has been used for building-purposes. Louth Abbey was in great part constructed of it. Near Louth this series contains a well marked bed of Red Chalk, 5 or 6 feet in thickness, and some other bands of a pinkish hue, all distinct from and much above the Hunstan-

ton limestone. The 'Sponge-bed' with *Spongia paradoxica* is found at the base of the Chalk series, graduating into the Hunstanton limestone. The Wolds of Lincolnshire are much more covered with superficial deposits than the downs of the south of England, or even Norfolk; hence the district of the Chalk in this county does not present that uniformly bare and arid appearance so characteristic of it in most parts; in fact, nearly the whole of it has now been brought under the plough, and with the most satisfactory results.

In Norfolk the Chalk was divided by Mr. Samuel Woodward into:—

Upper Chalk, with flints.
Medial Chalk, with few flints.
Lower or Hard Chalk.
Chalk Marl.

The thickness of the Chalk-with-flints (Upper and Medial) was proved to be 1,050 feet in a well-boring at Messrs. Colman's at Norwich; and that of the Chalk-without-flints (including the Hard Chalk) 102 feet. The Chalk Marl is only about 3 feet in thickness, and it is in a bed of white Chalk occurring at the base of it at Hunstanton that the *Spongia paradoxica* is found: this bed, called the Sponge Bed, is scarcely 18 inches in thickness, and may represent the Upper Greensand.[1] (See p. 238.)

The Hard Chalk has been much used for building-purposes. It has been largely quarried at Stoke Ferry and Whittington; it has yielded *Ichthyosaurus campylodon;* also *Ammonites peramplus*, and *A. Austenii*, each about 2 feet in diameter.

The Upper Chalk (very rarely the Medial Chalk) is characterized by the presence of the gigantic flints termed paramoudras or potstones, often 3 feet in length and 1 foot in

[1] Mr. Rose has estimated the maximum thickness of the Chalk at Norwich at 1,192 feet.

diameter, which are found at Horstead, Sherringham, Thorpe, &c.[1] Remains of *Leiodon anceps*, a Lacertilian reptile allied to *Mosasaurus*, have been obtained by Mr. T. G. Bayfield at Lollard's Pit, Norwich. But the very highest beds of chalk known in Norfolk are those which occur at Trimmingham, and which contain fossil sponges in the flints, only found elsewhere in the coarse flint-gravel which caps Mousehold Heath, near Norwich. (See fig. 21, p. 287.)

Mr. Whitaker has thus divided the Chalk of Buckinghamshire and neighbouring counties:—

	Feet
Chalk-with-flints	300
Chalk-rock, a thin hard cream-coloured bed with green-coated nodules, about	4
Chalk-without-flints, or with a very few flints in the uppermost part	400 to 500
Totternhoe stone, generally two layers, of hard and rather brownish sandy chalk, with dark grains	6
Chalk marl with stony layers	80

The Totternhoe stone has been largely quarried for building-purposes and to be burnt for lime. It is a water-bearing stratum; springs are thrown out at its base.

In Oxfordshire and Berkshire the thickness of the Chalk is pretty much the same as in Buckinghamshire; the Chalk-rock being from 6 to 12 feet.

In Wiltshire the total thickness of the Chalk is about 800 feet. According to Prof. Buckman the Chalk Marl (rich in Ammonites) varies in thickness from 20 to 50 feet, and generally throws out the springs of the Chalk, but these often become dry in summer: hence the names Winterbourne Basset, Winterbourne Monckton, &c., which have been given to the villages in the district.

[1] Lyell has noticed that some of the pear-shaped masses of flint often resemble in shape and size the large sponges called Neptune's Cups (*Spongia patera*), which grow in the seas of Sumatra. Mr. F. Kitton has advocated the spongeous origin of flints.

In Dorsetshire the Chalk has been divided by De la Beche into:—

Chalk-with-flints (146 feet).
Chalk-without-flints.
Chalk-with-quartz-grains.

The Lower beds of the Chalk are very nodular. Here, indeed (as Mr. Whitaker remarks), it is often hard to mark the junction; the Chalk gets darker, and harder, until it seems almost one mass with the Greensand. At the mouth of the Axe, the bed with quartz-grains is about three feet thick, and contains fossils.

Westward of Seaton the famous Beer Stone is met with. It consists of a series of beds of tolerably hard chalk, about 12 feet in thickness, the whole resting on the Greensand. Its occurrence is local, but this fact is significant as showing the variable nature of the Chalk. The bed has been worked, or rather mined, for very many years; portions of Exeter Cathedral were built of it.

There is no hard line anywhere in the Chalk series: the flintless beds appear to attain a maximum thickness of at least 50 feet, and the Chloritic Marl, the rich fossiliferous bed, forms the true base of the Chalk and is most properly included with it.

Mr. Whitaker has noticed the overlap of the Upper Chalk-with-flints on to the Greensand at Beer Head. He also identified the Chalk-rock in places in Dorsetshire and Devonshire.

On the Dorsetshire coast east of Weymouth the Chalk is very much disturbed, the bedding being in some places vertical or even reversed. The thickness near Weymouth is estimated at 800 feet.

In the Isle of Wight Mr. Charles Barrois has identified the following palæontological divisions which were established by Prof. E. Hébert in the north of France:—

		Feet
Chalk-with-flints	Zone of *Belemnitella*	265
	" " *Micraster cor-anguinum*	525
	" " " *cor-testudinarium*	165
	" " *Holaster planus*	65
Chalk Rock (8 to 10 ins.)	" " *Terebratula gracilis*	65
Chalk-without-flints	" " *Inoceramus labiatus*	130
Chalk Marl [1]	" " *Turrilites and Scaphites æqualis*	115
Chloritic Marl	" " *Ammonites laticlavius*	6

At Culver Cliff the Chalk dips at a very high angle, and on the opposite side of the Island, at Alum Bay, it is nearly vertical. (See fig. 20, p. 274.)

In Surrey the Chalk is from 350 to 500 feet in thickness. Mr. C. Evans has divided the Chalk near Croydon and Oxtead into stages according to the zones of fossils locally developed there:—

Upper Chalk. 250 feet.	PURLEY BEDS, with layers of flint nodules and thin tabular flint, *Micraster cor-anguinum* and *Inoceramus Cuvieri*.
	UPPER KENLEY BEDS, with layers of flint, nearer together than in above division, *Micraster cor-anguinum*, *Ananchytes ovatus*, *Spondylus spinosus*.
	LOWER KENLEY BEDS, with flints wider apart, *Holaster planus* and *Micraster cor-bovis*.
Middle Chalk. 75 feet.	WHITELEAF BEDS, with few or no flints, *Inoceramus Brongniarti*, and *Galerites albogalerus*.
Lower Chalk. 190 feet?	UPPER MARDEN PARK BEDS, without flints, *Ammonites peramplus*, and *Inoceramus mytiloides*.
	LOWER MARDEN PARK BEDS, grey chalk and chalk marl, with *Ammonites varians*, *Belemnitella plena*.

In East Kent the thickness of the Chalk has been estimated at upwards of 800 feet.

In the Isle of Thanet, as described by Mr. Whitaker, the

[1] This bed is called the 'Craie glauconieuse' by Prof. Hébert; but as the Chloritic Marl is glauconitic, the term Chalk Marl seems preferable, more especially as a nodular bed, found at the base of the chalk with *Inoceramus labiatus*, is regarded as corresponding to the Totternhoe stone which Mr. Whitaker places at the top of the Chalk Marl.

upper beds of the Chalk contain very few nodular flints, so that the bedding is not well shown: sometimes thin layers of flint fill the narrow vertical openings of the even joints. These beds he calls the Margate Chalk; they have a thickness of about 80 feet. Below, the series called the Broadstairs Chalk is distinguished by containing layers of tabular and nodular flint. The Margate Chalk contains fossils identical with those of Norwich, where the upper beds have been compared to the Chalk of Maestricht in Holland and Faxoe in Denmark, in which countries the Chalk exhibits gradations into the Tertiary strata above.

An excellent description of the Chalk of Dover was published many years ago by William Phillips, and the following Table shows the chief divisions which he made; to these are appended some local names and the palæontological zones determined by Prof. Hébert:—

Chalk with few flints (Margate Chalk)	
Chalk with numerous flints:	*Micraster cor-anguinum.*
(*b.* Broadstairs Chalk = Ramsgate Chalk[1]	,, *cor-testudinarium.*
a. St. Margaret's Chalk [1])	*Holaster planus.*
Chalk with few flints (Dover Chalk [1]) . .	*Inoceramus labiatus.*
Chalk without flints	
Grey Chalk, Chalk Marl	

One of the most interesting discoveries in the Chalk was that of a Granitic boulder at Purley near Croydon, described by Mr. Godwin-Austen. It was originally about 3 feet long, and was accompanied by some decomposing fragments of a felspathic rock and with a compact mass of siliceous sand. Mr. Godwin-Austen considered that an ice-floe was the agent by which alone such a block could have been lifted from the coast and conveyed far out to sea.

At Grays Thurrock the thickness of the Chalk is upwards of 660 feet: at Harwich it was proved to be 888 feet, and at Kentish Town 640 feet. (See fig. 19, p. 257.)

[1] These names were given by Mr. G. Dowker.

Economic Products, &c., of Chalk.

The Chalk Downs produce a scanty herbage, to which sheep are largely devoted.

In some parts good crops of barley, turnips, and wheat are produced. The Lower Chalk and Chalk Marl are, as a rule, more fertile than the Upper Chalk. The ponds generally require to be clayed.

The Chalk Downs are considered to retain their ancient character more than any other tracts of country. Beech trees grow exceedingly well on the Chalk where covered with clay-with-flints or brickearth, and in Buckinghamshire they are largely used for Chair-making.

In many places there is no durable stone save the scattered 'Sarsens.'[1] In other places, as before mentioned, hard beds have been worked for building-purposes.

The flints are largely used for road-metal and for building-purposes. When burnt and ground they are employed in the manufacture of china, porcelain, and flint-glass.

Gun-flints in former times were largely manufactured from the chalk-flints, and are still made at Brandon and Norwich for export to Africa.

The Chalk pits vary from 50 to 150 feet in depth. The men work at the top of the pits with levers (or where the chalk is very hard, with gunpowder),[2] and throw the Chalk down in great masses, which break to pieces in their fall. The joints are taken advantage of in excavating the Chalk.

The Chalk is extensively burnt for lime: it is also prepared for whiting at Grays, Kintbury,[3] and other places.

[1] These will be described in the sequel.

[2] The most remarkable blowing up of Chalk took place some years ago at the Round Down Cliff, Dover, when hundreds of tons were thrown into the sea to make an opening for the railway beneath the cliff.

[3] The whiting is prepared by grinding the soft Upper Chalk, dug on the spot, to a fine pulp with water, and allowing the whole to flow into

Sulphuretted hydrogen, produced by the decomposition of iron-pyrites and water, is sometimes rather troublesome to well-sinkers, and Carbonic acid gas (Choke damp) is apt to accumulate in tunnels and borings in Chalk.

The Chiltern Hills and the North and South Downs are everywhere celebrated for the extent of their prospects. The boldness of the escarpment and the whiteness of the substance have given the idea of ornamenting the country in various parts by cutting away the turf. The White Horse, above Uffington in Berkshire, occupies about an acre of ground, and may be seen from some points of view at the distance of twelve miles. There is another land-mark of the same kind at Chervil, near Calne in Wiltshire, and a third in the neighbourhood of Thetford. On the chalk hill that faces Weymouth is a representation of George III. on horseback. Near Cerne is a figure of a giant holding a club in one hand and extending the other; this colossal figure is 180 feet in height. Near Prince's Risborough a large Cross has been cut.[1]

a series of tanks or reservoirs connected with each other. The sediment is formed into cakes and dried. (H. W. Bristow.)

[1] These notes are partly taken from Conybeare and Phillips, *Geology of England and Wales.*

SECTION III.

TERTIARY OR KAINOZOIC.[1]

Chapter IX.

EOCENE, MIOCENE, AND PLIOCENE.

Our English Tertiary strata when looked at in a large way stand out in marked contrast to the Secondary and Palæozoic strata by reason of their lithological characters. They are composed for the most part of soft clays, and sands, with occasional pebble-beds. The marked lines of stratification so conspicuous in most of the Secondary strata are not recognized, and naturally, because the beds are less consolidated. We see in them the transitional strata between the rocky or stony formations and the recent deposits. The organic remains now begin to approach very closely to existing types: every stage brings us into contact with forms nearer to those now living.

It was for this reason that Lyell proposed the terms Eocene, Miocene, and Pliocene for the three great divisions into which European Tertiary deposits had been divided. These terms were based upon the percentage of recent mollusca found in the strata to which they were applied. Thus the Eocene strata (dawn of recent) contain a very small proportion of living species; the Miocene strata (less recent), although containing more recent species, yet contain a minor

[1] The term Kainozoic (Cainozoic, or Cænozoic) signifies *recent life.*

proportion compared to the Pliocene strata (more recent), which contain a plurality of recent species.

The Tertiary strata are characterized by numerous genera of large Mammalia, many genera and species of Mollusca identical with those now living, and dicotyledonous plants.

EOCENE.

The Eocene strata have been divided and sub-divided as follows, and mainly from the researches of Prestwich, and Edward Forbes:—

EOCENE.	Upper	Hempstead Beds.[1]	Corbula Beds.		Fluvio-Marine Series.
			Upper Middle Lower	Freshwater and Estuary Marls.	
		Bembridge Beds.	Bembridge Marls. " Limestone.		
		Osborne Beds.	St. Helen's Sands. Nettlestone Grits.		
		Headon Beds.	Upper Middle Lower		
	Middle	Bagshot Beds.	Upper Bagshot Sand.		
			Middle "	Barton Clay. Bracklesham Beds.	
			Lower "	Sand and Pipeclay, with Pebble-beds.	
	Lower	London Tertiaries.	London Clay and Bognor Beds (Upper London Tertiaries).		
			Oldhaven Beds. Woolwich and Reading Beds (Plastic Clay). Thanet Beds.		Lower London Tertiaries.

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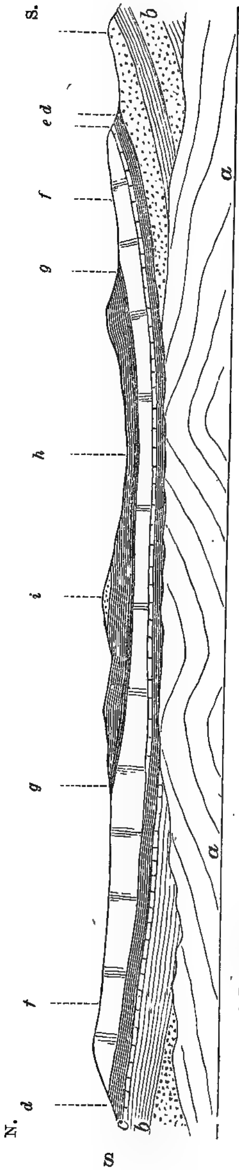
[1] The Hempstead Beds have by some geologists been regarded as Miocene.

The Eocene strata occupy two distinct tracts, termed respectively the London and Hampshire Basins. The basin-like arrangement of the Chalk strata upon which these newer deposits lie, is, perhaps, most conspicuous in the Hampshire district, which includes the Tertiary beds of Dorset, Hants, the Isle of Wight, and Sussex. In the London Basin the sea-ward extension of the strata on the east is unknown, but wherever observed the beds rest upon a foundation or basin of Chalk. The formation of these Basins is due to upheaval and denudation subsequent to the Eocene period.

Although there is nowhere any marked unconformity in stratification between the Chalk and overlying Tertiary strata due to erosion in pre-Tertiary times, yet the change from deep-sea conditions to those of comparatively shallow-water is abrupt: the 'pipes,' or irregular-shaped hollows, that have been dissolved out of the Chalk by the action of carbonated water, are features that may have been produced after the deposition of the newer strata. Nevertheless most of the lower Tertiary beds contain pebbles formed of flint evidently due to destruction of the Chalk; and when we also take into consideration the fact that in Denmark and Holland there are passage-beds between the Cretaceous and Tertiary formations which we do not find to be represented in England, the natural conclusion is that in our country these two great groups of rocks are unconformable.

Fig. 19.—*General Section of the London Basin, showing the probable ridge of old rocks.*

(W. Whitaker.)



i. Lower Bagshot Beds.
h. London Clay.
g. { Oldhaven Beds. Woolwich and Reading Beds. Thanet Beds.
f. Chalk.
e. Upper Greensand.
d. Gault.
c. Lower Greensand.
b. Wealden and Oolitic Beds.
a. Palæozoic Rocks.

LOWER EOCENE.

THANET BEDS.

The name 'Thanet Sands' was given by Mr. Prestwich from the fact that they are best exhibited, and marked by organic remains, in part of the Isle of Thanet and adjacent country.

The series consists of pale-yellow quartzose sand and loam, with an admixture sometimes of greenish particles, and forming, according to Mr. Prestwich, an impure argillaceous greyish greensand. He states that a marked feature is the occurrence of green-coated flints at the base of the deposit, and immediately reposing on the Chalk.

The thickness of the beds is variable: under London it is about 20 feet, in West Kent upwards of 60 feet. Mr. Whitaker has made out the following subdivisions in the Thanet Beds:—

(*e*) Fine sharp light-grey sand, slightly greenish, often iron-shot, with layers of calcareous sandstone here and there; the fossils sometimes silicified; thins eastward, and is almost confined to East Kent, where it attains about 40 feet in thickness, and passes down into—

(*d*) Bluish-grey sandy marl, weathering to a pale yellowish-grey, often rather hard, with green grains and fossils, more sandy at top; thins westward, and is almost confined to East Kent, where it is the thickest member of the series near and beyond Canterbury.

(*c*) Fine light-buff sand, mostly soft, with few fossils (only some very obscure remains have been found); it is thickest in West Kent (up to 60 feet or more), where for the most part it forms nearly

the whole of the Thanet Beds, thinning out westward in Surrey, and eastwards in Kent.

(*b*) Alternations of brown clay and loam, without fossils, thin and local (to part of East Kent).

(*a*) The 'base-bed,' clayey greensand, with unworn green-coated flints, resting on the Chalk, thin (rarely over 5 feet) but constant.

Mr. Whitaker mentions that in every large section the junction between the Chalk and Thanet Beds is even; where, however, there is but a thin capping of the latter, it often fills 'pipes,' irregular-shaped hollows, that have been formed since the deposition of the beds, by the infiltration of water with carbonic acid in solution.

He doubts there being proof of any 'eroded surface' of the Chalk (that is to say, a surface worn down before the deposition of the succeeding beds) below the older Tertiary formations in England, whether it is overlaid by the Thanet Beds, or, in their absence, by the Woolwich and Reading Beds: an uneven surface is not of necessity an unconformable one.

The Thanet Beds yield remains of Mollusca, Polyzoa, Crustacea, Entomostraca, Echinodermata, Spongida, Foraminifera, and Plants. Among the more prominent species are the Mollusca *Cyprina Morrisii*, *Pholadomya cuneata*, *Corbula Regulbiensis*, and *Aporrhais Sowerbyi*.

The beds are well exposed in the cliffs of Pegwell Bay, in those east of Herne Bay, and in pits at Charlton near Woolwich and the south of London; they are met with in deep wells under London, but do not extend further west than Windsor, nor do they occur in the Hampshire Basin.

Their occurrence near Sudbury on the northern side of the London Basin had not been noticed until recently, when Mr. Whitaker drew attention to them.

The Thanet Beds are a marine deposit of shallow water, formed in a sea open to the north.

The deposit of green-coated flints at the base is considered by Mr. Whitaker and Professor Hughes to have been formed after the deposition of the Thanet Sand by the decomposition of the top of the Chalk.

In Berkshire Mr. Whitaker has sometimes noticed a bed of reconstructed chalk immediately overlying the Chalk and capped by Reading Beds. This reconstructed bed, which may be 20 feet in thickness, contains blocks of chalk, scattered lines of flint, and much rubbly chalk. It may possibly have been formed at the period when the Thanet Sands were elsewhere deposited.

Allophane (Hydrous silicate of alumina) occurs at the junction of the Thanet Beds and Chalk at Charlton near Woolwich, and Silicified wood is met with in the Thanet Beds in East Kent.

WOOLWICH AND READING BEDS.

Plastic Clay.

This series, named by Mr. Prestwich from the localities where it is characteristically developed, consists of alternations of plastic clay, loam, and sands variegated in colour, and of pebble-beds of rolled flint, which are sometimes hardened into pudding-stone.

The thickness of the beds varies from 15 to 90 feet in the London Basin; and in the Isle of Wight from 84 feet in Alum Bay to 163 feet in Whitecliff Bay.

It has been shown, and mainly through the researches of Mr. Prestwich, that three distinct conditions of the Woolwich and Reading series are developed.[1]

[1] See Whitaker, *Mem. Geol. Survey,* vol. iv. pp. 98, 99.

1. In the Hampshire Basin, and in the London Basin all along the northern outcrop, and on the western part of the southern outcrop from Berkshire through North Hampshire and the greater part of Surrey, this series is generally unfossiliferous. It consists of irregular alternations of clays and sands; the former of many and bright colours, mostly mottled and plastic; the latter also of many colours, both coarse and fine, sometimes with flint pebbles, and now and then hardened into sandstone or conglomerate; loam also occurs.

2. In the eastern border of Surrey, in West Kent, the border of East Kent, and partly in South Essex, we find, with the light-coloured sands, finely-bedded grey clay, mostly crowded with estuarine shells, and often with oyster-shells compacted into rock. Above this there is often (on the south-east of London) a fairly thick bed consisting of thin alternations of sand and clay, or loam; at the base of the shelly clays there is generally a bed of imperfect lignite, and lower down sometimes a pebble-bed.

3. In East Kent we find the simplest state of this formation, which there consists throughout of light-coloured sharp false-bedded sand with marine fossils, differing alike from the estuarine Woolwich Beds and the changeful Reading Beds. One part of the formation is fairly constant. Where it rests on the Thanet Beds this lowest member of the Woolwich and Reading Series is a greensand, more or less clayey, with flint-pebbles and here and there oyster-shells. Where, however, it rests on the Chalk it is usually of a more clayey character; the flints at its base are angular and green-coated, instead of being in the state of perfectly rolled pebbles; as before, there are sometimes oyster-shells in the greensand, and besides there are (somewhat rarely) casts and impressions of other shells in the accompanying roughly laminated grey clays (with green grains). The difference in the condition of the flints in the two cases is just what one

would expect: in the latter they have been got direct from the underlying Chalk, whilst in the former they must have been carried some distance, and therefore worn. Although sections do not show any unconformability between this formation and the Chalk, yet there may be some unconformability, so gradual that it can be inferred only by the comparison of a series of distant sections. (Whitaker.)

The fossils of the Woolwich and Reading Beds include Mammals, Birds, Reptiles, Fishes, Mollusca, Polyzoa, Crustacea (including Entomostraca), Spongida, Foraminifera, and Plants.

The tapir-like *Coryphodon* has been met with in these strata, also Turtles among the Reptiles. The Mollusca include *Ostrea Bellovacina*, *Melania inquinata*, *Cyrena cuneiformis*, *C. Dulwichiensis*, *Unio*, *Paludina*, *Pitharella*, &c.

The Bottom bed is often termed the Oyster-bed from the frequent abundance in it of *Ostrea Bellovacina*.

At Loam Pit Hill, near Lewisham, the Woolwich Beds have been well exposed: indeed the succession is complete from the Chalk to the London Clay. The thickness of the Woolwich Beds here is about 50 feet, and comprises light-coloured sand, laminated clay, a shell-bed with *Ostrea* and *Cyrena*, and a pebble-bed 12 feet in thickness.

At Peckham the Paludina-bed or Cockle-bed, a thin layer of grey clayey limestone, occurs near the top of the Woolwich Beds; it contains *Paludina lenta*. At this locality Mr. Rickman first noticed *Pitharella* and *Cyrena Dulwichiensis*.

The Hertfordshire pudding-stone is composed of flint pebbles embedded in a siliceous matrix, and so firmly cemented that the pebbles are fractured equally with the matrix.

In the Isle of Wight the beds may be studied in White-

cliff and Alum Bays; they consist of mottled clays and sands, and have a thickness of 84 feet, according to measurements by Mr. Bristow. (See fig. 20, p. 274.)

In Dorsetshire the strata are exposed at Studland Bay, and there are some beds of plastic clay near Weymouth which have been referred to the Woolwich and Reading Series, as also the pebble-beds and sands of Bincombe Heath.

Fuller's Earth is said to have been found in the Reading Beds at Katesgrove Kiln, Reading.

The beds are largely used for brickmaking, also for coarse pottery; and sometimes pipe-clay is found in them.

Websterite (Hydrous sulphate of alumina) occurs at the junction of the Tertiary beds and Chalk at Newhaven and Brighton in Sussex, and to the south of Bromley in Kent.

OLDHAVEN BEDS.

This name was given by Mr. Whitaker in 1866 to the sands and pebble-beds that come between the London Clay and Woolwich Beds in Kent, which before that had been doubtfully classed by Mr. Prestwich with the basement-bed of the London Clay, and to a small extent with the Woolwich Beds. The true basement-bed of the London Clay may sometimes be seen overlying the Oldhaven Beds. The name is taken from Oldhaven Gap, on the coast of Kent, west of Reculvers, where the beds are well displayed.

The formation consists almost wholly of perfectly rolled flint-pebbles in a fine sandy base, or of fine sharp light-coloured quartzose sand, and it occasionally contains limonite. Current-bedding is displayed in places. Sometimes the pebble-beds are cemented into a hard rock, or pudding-stone. The total thickness of the beds varies from 20 to 30 feet.

In the neighbourhood of Canterbury, at Shottenden Hill,

near Sittingbourne and Rochester, at Plumstead Common, Abbey Wood, Blackheath,[1] and Woolwich, the beds are well displayed. They thin out in the neighbourhood of Lewisham, and are not met with under London, nor in the western part of the London Basin.

The Oldhaven Beds are often fossiliferous. The fossils are partly estuarine and partly marine, being sometimes the same as those of the Woolwich Beds below, and sometimes more nearly approaching those of the London Clay above, seeming therefore to prove oscillations of surface or changes of current and nearness to land, conditions which might also be expected from the masses of pebbles. It would seem that these old pebble-beds were not formed as a beach along a chalk-shore, as in that case they should contain many flints but partly worn, and one is led therefore to infer that they must have been deposited some way off the shore, as a bank to which no flints could get until after having been long exposed to wearing action. (Whitaker.)

Sands of doubtful age.—In certain localities on the Chalk in Kent and Surrey there have been found traces of sand and clay and iron-sandstone with casts of mollusc-shells, mostly bivalves; these deposits sometimes fill pipes in the Chalk, and have been met with at Headley, Chipsted, Paddlesworth, Lenham, &c. The examination of the beds by Mr. Prestwich, and a study by Mr. Wood of the fossils which have been found in two or three of the pipes (all of these, however, were very obscure), led to their being doubtfully referred to the Crag; but both Mr. Bristow and Mr. Whitaker incline to refer most of them to the Eocene period, regarding them as representatives of Woolwich or Oldhaven Beds. (See p. 280.)

[1] Blackheath Beds.

LONDON CLAY.

This formation, so named by William Smith, consists of stiff brown and bluish or slate-coloured clay, containing layers of septaria or cement-stones. At its base it displays sandy and loamy beds containing flint pebbles, and sometimes 'cemented by carbonate of lime into semi-concretionary tabular masses;' this is called the 'Basement-bed' of the London Clay by Mr. Prestwich. The top strata are also sandy, passing up into the Lower Bagshot Beds above.

The surface of the London Clay frequently weathers into a loam. Mr. Whitaker observes that the brown colour at and near the surface is merely a colour of decomposition; the protosalt of iron that gives the bluish tint peroxidating by exposure to atmospheric action. The London Clay contains much iron-pyrites and selenite. Its thickness varies from next to nothing in Wiltshire, and from 50 or 60 feet in Berkshire to nearly 500 feet in the south of Essex.

The London Clay yields a very extensive list of fossils, and, although specimens are abundant, it is not always easy to find them, as they occur in groups or zones conspicuous at one locality and not seen at all at the same horizon in another.

Among these organic remains are species of Mammals, Birds, Turtles, Crocodiles, Fishes, Mollusca, Crustacea, Entomostraca, Cirripedia, Annelida, Echinodermata, Actinozoa, Protozoa, and Plants.

Specimens have been obtained at Pebble Hill (near Hungerford), Newnham and Cuffell (near Basingstoke), Bognor, Highgate, Finchley, Holloway, Harwich, Sheppey, &c. At the last-named place were found in greatest abundance the fossil fruits described by Dr. Bowerbank; amongst these the palm *Nipadites ellipticus* is conspicuous. The Mollusca include *Pectunculus brevirostrum*, *Panopæa*, *Cryptodon*

angulatum, *Fusus*, *Pleurotoma*, *Rostellaria ampla*, *Voluta nodosa*, *Nautilus centralis*, *N.* (*Aturia*) *ziczac*, *N. imperialis*, &c. The Annelide *Ditrupa plana* is common, and sometimes fossil wood with *Teredo*-borings is met with.

The London Clay is a marine formation, and Mr. Prestwich considers that its fauna indicates a moderate rather than a tropical climate, although the flora seems to be certainly tropical in its affinities. The lithological characters, he states, denote a tranquil and uniform deposit, of considerable duration, accompanied by a quiet and gradual subsidence of the bed of the sea. Prof. T. Rupert Jones remarks that the indication of sea-depth for the London Clay, afforded by the Foraminifera, is that the water was about 100 fathoms deep. The proximity of land is indicated by the remains of plants, mammals, and reptiles.

Amongst the reptiles were many turtles, also the sea-snake *Palæophis* (probably about thirteen feet in length), and the Crocodile (*C. toliapicus*). The *Odontopteryx* found at Sheppey is considered by Prof. Owen to have been a web-footed bird having jaws provided with bony teeth.

The *Hyracotherium* (allied to the living Hyrax), also the tapir-like *Lophiodon* and *Coryphodon*, are found in the London Clay.[1]

Bognor Beds.—On the shore near Bognor in Sussex are exposed beds of clay and calcareous sandstone, and so far as the series can be made out it comprises alternations of sands and clays with pebble-beds. Similar beds are developed at Portsmouth. They have generally been placed on the horizon of the lower part of the London Clay, but Mr. C. Evans has recently pointed out the difficulty of paralleling the organic

[1] A deposit of yellow and white sand belonging to the basement-bed of the London Clay at Kyson near Woodbridge has yielded Mammalian remains of the genus *Hyracotherium* (the teeth of which were originally considered to belong to a Monkey) and also *Didelphys*.

remains in the deposits of Hants and the London Basin, while at the same time the variation in mineral character would seem to render it desirable to retain the distinctive term of Bognor Beds.

The Barns Rocks between Selsea and Bognor, the Roundgate and Street rocks on the west, and Mixen rocks to the south of Selsea, are portions of the same bed: similar masses also appear at Stubbington.[1]

In the Isle of Wight about 50 feet from the basement-bed is a band of *Ditrupa plana*, called the Ditrupa-band. The junction with the Woolwich and Reading Beds is sharp and well-defined, and both in Alum and Whitecliff Bays the division is indicated by a band of flint-pebbles—the basement-bed of Mr. Prestwich. At about thirty-five feet above the basement-bed there is a zone of *Panopæa intermedia*, and *Pholadomya margaritacea*; at fifty feet a band of *Ditrupa plana*; and at about eighty feet a band of *Cardita* occurs. (See fig. 20, p. 274.)

Fossil copal (Copaline) or Highgate resin was discovered during the excavations for the Highgate Archway.

The London Clay is everywhere very extensively used for brick- and tile-making.

Septaria or Cement-stones have been largely used in the manufacture of Roman cement. For this purpose they have been dredged in Chichester Harbour, at Harwich, and off the coast of Hampshire: they have also been collected near Southend.

'The septaria on the south of Walton on the coast of Essex are very imperfect; they are collected into heaps on the Nore, and shipped to Harwich, where they are manufactured by Government into a cement. Dale, in his History of Harwich (p. 101), speaking of the septaria so abundantly found in the cliffs of the neighbourhood, says, "with these the walls of the town were for the most part built, and the streets generally pitched, they by ancient custom belonging to the town as their right."

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[1] Conybeare and Phillips.

The long cliff of the London Clay extending along the northern side of Sheppey Isle furnishes abundance of Septaria, from which that excellent material for building under water and for stucco is made, and which is known by the name of Parker's Cement. Being separated from the clay by the action of the sea, they are collected on the beach, and exported to various places where they are calcined and ground.

'In Hampstead and Highgate Hills in Middlesex, and in Boughton Hill in Kent, the layers of septaria occur about 50 feet below the summit. In Shooter's Hill they are very near the surface. At Epping, they were not found nearer than 100 feet beneath the grass, and continued to the depth of 300 feet.'[1]

The London Clay forms a stiff tenacious soil, making good pasture-land, and yielding by the application of marl good crops of corn.

Teazles are cultivated in Essex, and elm, oak, and ash timber in different places. The London Clay is impervious, and yields no water save in the basement beds.

MIDDLE EOCENE.

BAGSHOT BEDS.

Lower Marine (old authors).
Bagshot Sand (Warburton, 1821).

The structure of the Bagshot Beds, so named from Bagshot Heath in Surrey, was first elucidated by Mr. Prestwich, who ascertained that they could be divided into three distinct and persistent divisions, severally characterized by peculiar groups of organic remains and by differences of lithological characters, thus:—

Upper Bagshot Beds.
Middle Bagshot Beds $\left\{\begin{array}{l}\text{Barton Clay.}\\ \text{Bracklesham Beds.}\end{array}\right.$
Lower Bagshot Beds.

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[1] Conybeare and Phillips.

The series is perfectly conformable, and it is difficult to draw any hard lines between the divisions.

Lower Bagshot Beds.

This deposit consists of pale yellow or buff-coloured siliceous sand and loam, with seams of pipe-clay, and occasional beds of flint-pebbles. Ironstone veins and nodules are sometimes met with. The thickness varies from 100 to 150 feet.

In the London Basin the beds locally show no inclination, but they are generally disposed with a slight dip to the south-east: in the Isle of Wight they are highly inclined. (See fig. 20, p. 274.)

Organic remains are exceedingly rare, only a few casts of mollusca having been found.

The Leaf-beds (pipe-clay) of Alum Bay and Bournemouth have yielded many land-plants of sub-tropical genera, such as palms, maples, &c.

Mr. Prestwich considers that the Lower Bagshot Beds were derived by denudation from the older crystalline and granitic rocks, but Mr. G. Maw has suggested that some of the fine white clays may have been due to the destruction of the Chalk.

The pebble-beds in the Lower Bagshot series were first determined by Mr. S. V. Wood, jun. They occur at Brentwood, Stock, Billericay, and other localities in Essex. Their maximum thickness is 15 feet at Brentwood, where the section shows:—

		Feet
Bagshot Beds	8. Pebble-beds	15
	7. Brickearth or loam 6. Sand	25
London Clay	5. Brickearth or loam 4. Clay 3. Sand, 2 or 3 feet 2. Brickearth or loam	50
	1. Clay, with Septaria.	

From the Bagshot Beds themselves varying so much in section, and from the passage upwards of the London Clay into them, it is impossible to be certain as to the horizon taken as the junction of the two formations in the many outliers of Essex. Where a purely sandy condition prevailed at one spot a loam may have been formed at another, and a clay at a third. Again the test of level avails but little when it is remembered to what changes the area has been subjected in later times, during and after the Glacial Period: nor is it likely that the beds were spread over a uniform level; so that taking these points into consideration, it seems that the boundary between the Bagshot Beds and the London Clay must be drawn mainly with reference to the features of each outlier.

Probably the best place for studying the Bagshot Beds in Essex is Brentwood, where the structure of both the sands and pebble-beds, and also their relation to the London Clay, are clearly shown. In the sections there the London Clay is seen to pass upwards into the Bagshot Sand. The brickyards well show the passage-beds, which consist of alternations of clays, sands, and loams, furnishing excellent brickearths. This passage makes the boundary-line between the two deposits very indefinite, and that line is liable to be taken at different horizons in different localities, even in the same outlier. There is no hard line anywhere, and it therefore becomes a matter of convenience, rather than of marked distinction, where to draw the boundary.[1]

Outliers occur at Langdon Hill, Rayleigh, High Beech, Highgate, Hampstead, and Harrow, forming some of the highest hills near London, and commanding extensive views: that from Langdon Hill in particular being surpassed by few in England.

The beds are exposed in Alum and Whitecliff Bays in

[1] Notes by H. B. W. in *Mem. Geol. Surv.* vol. iv. part 1.

the Isle of Wight; at the former locality they attain a thickness of upwards of 660 feet. They are described by Mr. Bristow as a series of variously coloured unfossiliferous sands and clays, with seams of lignite and iron-sandstone. The clays are crowded with land-plants of sub-tropical genera.

Mr. Bristow observes that the flora of Alum Bay (Alum Bay leaf-bed) is more especially distinguished by the number and variety of its *Leguminosæ*, four species of which are known. The vegetation thus approximates to that of the London Clay. Fig-trees of lofty proportions, with long thick leaves, fig-sycamores with more delicate heart-shaped leaves, an *Aralia* with palmated leaves, must from their abundance have imparted a singularly majestic aspect to the vegetation of the period.[1]

Similar plant-remains have been found at Bournemouth, Studland, and Poole, but the distribution of the genera varies at each locality.

The Poole Clay, so called from its being shipped at Poole, comprises beds of pipe and potter's-clay. It is worked between Wareham and Corfe, at Creech Grange, Nordon, and Rempstone; and is manufactured into ornamental tiles, tesselated pavements, &c. In the Isle of Wight this pipe-clay is almost entirely replaced by sands.

Middle Bagshot Beds.

In the Hampshire Basin these beds have been found to admit of two divisions:—

2. Barton Clay.
1. Bracklesham Beds.

The whole series is, however, represented by the lower type (Bracklesham Beds) in the London Basin.

Bracklesham Beds.—The Bracklesham Beds were so

[1] The plant-remains have been described by Dr. De la Harpe.

named from the remarkable series of strata displayed at Bracklesham Bay in Sussex.

They consist in Alum Bay, in the lower part, of clays and marls, overlaid by white, yellow, and crimson sands. The lower beds are remarkable for the lignite they contain, which is found in solid beds from fifteen inches to over two feet in thickness. Like true coal, each bed is based upon a stratum of clay, containing apparently the rootlets of plants. The deposit is a little more than 100 feet in thickness.

In Whitecliff Bay the series is thicker, and the lower beds, consisting of green clayey sands, yield *Cardita planicosta* and *Turritella imbricataria:* the former species giving name to the Cardita bed.

According to Mr. Bristow a hard bed of conglomerate, formed of rounded flint-pebbles, constitutes a strongly defined division between the Bracklesham Beds and Barton Clay.

In Bracklesham Bay these deposits are often covered up with a few inches of sea-sand, and are only occasionally exposed to view.

In Berkshire the Bracklesham Beds have a thickness of about 20 feet, and consist of alternations of grey clays, white pipe-clays, and white and yellow sands with pebbles.

Barton Clay.—The Barton Clay, so well exposed in the cliffs of Barton and Hordwell in Hampshire, consists of grey and bluish-green clay and sands with septaria, altogether attaining a thickness of 300 feet.

The Clays are very fossiliferous, and contain *Rostellaria rimosa, Voluta luctatrix, Fusus longævus, Typhis pungens, Phorus, Calyptræa, Sanguinolaria compressa, Crassatella sulcata, Nummulites,* &c.

The Clay is used for making bricks.

Upper Bagshot Beds.

This division comprises white and pale-yellow, sometimes

mottled, sands showing no distinct lines of bedding, and containing few traces of organic remains. Mr. Prestwich states that the well-known blocks of light-coloured, or marly white, saccharine sandstone are met with chiefly in the upper beds of these sands, generally just below the Drift gravel. They are found by sounding the sands and gravel with iron rods. Some of these concretions attain a size of 10 to 12 feet across, and are 3 to 4 feet in thickness. Flint-pebbles, sometimes only slightly rolled and angular, at other times perfectly rounded, occur in them. The sandstone is friable when first excavated, but hardens by exposure.

The Upper Bagshot Beds attain a thickness of from 250 to 300 feet. They are best exhibited on Frimley and Chobham Ridges, which are formed entirely of them, and in the heaths of Bagshot, Hartford Bridge, and Sandhurst. Their thickness in the Isle of Wight is estimated by Mr. Bristow at from 140 to 200 feet: here they are of considerable economic value, on account of their whiteness and purity, which render them particularly suitable for making glass, for which purpose they have been extensively worked for many years. Being developed at Headon Hill, they have been known as the Headon Hill Sands.

UPPER EOCENE OR FLUVIO-MARINE SERIES.

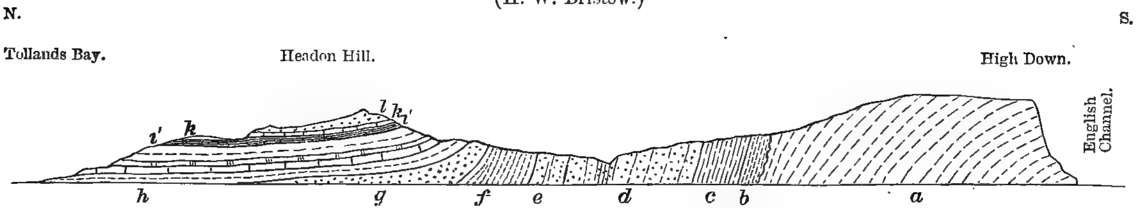
The term Fluvio-Marine Series has been applied to the Headon, Osborne, Bembridge, and Hempstead Beds, because they are partly of freshwater and partly of estuarine or marine origin. They are most completely developed in the Isle of Wight, where their relations and palæontological contents were systematically worked out by Edward Forbes.

No members of the series are met with in the London Basin.

FIG. 20.

Section across Headon Hill and High Down, Isle of Wight.

(H. W. Bristow.)



l. Gravel and Sand.
k. Bembridge Beds.
i. Osborne Beds.
h. Headon Beds.
g. Upper Bagshot Beds.
f. Barton Clay.
e. Bracklesham Beds.
d. Lower Bagshot Beds.
c. London Clay (Bognor Beds).
b. Woolwich and Reading Beds.
a. Chalk.

HEADON BEDS.[1]

These beds, named from their occurrence at Headon Hill in the Isle of Wight, consist of green shelly sands and limestones, which were subdivided by Prof. Forbes as follows:—

Upper Headon[2] { Uppermost marls with *Cerithium lapidum*, and Upper Headon freshwater and brackish beds, and sands with *Potamomya*.

Middle Headon,[3] with *Cytherea incrassata* (Venus Bed), and *Neritina concava* (Neritina Bed).

Lower Headon,[4] fresh- and brackish-water beds, in which *Cyrena cycladiformis* is a marked shell. Thickness, 67 feet at Headon, and 40 feet in Whitecliff Bay.

The total thickness of the Headon Beds varies from 133 feet at Headon Hill to 175 feet at Whitecliff Bay. *Paludina lenta*, *Planorbis euomphalus*, *Limnæa longiscata*, *Potamides cinctus*, *Ostrea flabellula*, and *Chara Wrightii*, are the most abundant species. At Hordwell Mr. S. V. Wood obtained the *Spalacodon* (an insectivorous Mammal), also remains of Crocodile, Tortoises, &c.

According to Baron von Koenen (1864) railway-cuttings in the New Forest (Brockenhurst, &c.) have exposed certain marine beds overlying the Lower Headon (freshwater) series, and containing fossils hitherto unknown in England, but which he believes to constitute the marine equivalent of the Middle Headon strata.

OSBORNE BEDS.

These Beds, named by Prof. Forbes after the Royal demesne of Osborne, are subdivided into:—

2. St. Helen's Sands.
1. Nettlestone Grits.

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[1] The Headon and also the Osborne Beds are sometimes placed with the Middle Eocene.

[2] The Upper Freshwater formation of Webster.

[3] The Upper Marine formation of Webster.

[4] The Lower Freshwater formation of Webster.

The *St. Helen's Sands* comprise pale green, yellow, and white sands, hardening into sandstone, with white and yellow marls and clays, having a total thickness of about 80 feet.

The *Nettlestone Grits*, which underlie them, include beds of grit, soft sandstone, clay and limestone, having a thickness of about 20 feet.

The sections vary much in detail. They yield *Chara Lyelli*, *Limnæa longiscata*, *Paludina lenta*, *Melania excavata*, *Planorbis*, &c.

BEMBRIDGE BEDS.

This series was subdivided by Prof. Forbes into:—

Upper Bembridge Marl, consisting of marls and laminated grey clays, yielding in great abundance *Melania turritissima*.

Lower Bembridge Marl, comprising unfossiliferous mottled clays alternating with fossiliferous laminated clays and marls, with *Cerithium mutabile*, *Cyrena pulchra*, &c.

Bembridge Oyster Bed, a band containing *Ostrea Vectensis*.

Bembridge Limestone, comprising the uppermost shell-limestones of Headon Hill, Sconce, Hempstead Ledge, Gurnet Bay, Cowes, Binsted, Bembridge, &c. This limestone is sometimes hard and compact, at others soft and tufaceous. It contains *Bulimus ellipticus* (Bulimus limestone), *Helix globosa*, *Planorbis discus*, and *Limnæa longiscata* (Limnæan limestone).

The Bembridge limestone has been largely quarried at Binsted, East Cowes, &c.; but the beds are now seldom worked.

The Bembridge Beds have yielded remains of *Trionyx*; also the Mammalia, *Anoplotherium*, *Chœropotamus*, and *Palæotherium*.

HEMPSTEAD BEDS.

These beds, deriving their name from their occurrence at Hempstead, were divided by Prof. Forbes into:—

		Feet	inches
Corbula Beds, brown and greenish clay with shelly bands,	*Corbula pisum*, *C. Vectensis*, &c.	9	6
Freshwater and Estuarine Marls	Upper, containing *Cerithium plicatum*, *C. elegans*, *Corbula*, *Rissoa*, *Hydrobia*, *Melania*, *Paludina*, &c.	40	0
	Middle, with *Cyrena semistriata*, *Cerithium*, *Rissoa*, *Panopæa minor*, &c.	50	0
	Lower, with *Melania muricata*, *Melanopsis carinata*, *Cyclas Bristovii*, *Unio Gibbsii*, &c.	65	0

These beds have been classed as Lower Miocene by Sir Charles Lyell, as Prof. Heer has recognized among some plant-remains found in them, four species common to the lignite of Bovey Tracey.

MIOCENE.[1]

Until the year 1857 no traces of Miocene beds were suspected to exist in England; at that time attention was drawn to the lignites of Bovey Tracey in Devonshire; but it was not until 1860 that the question was finally settled. Then through the liberality of Miss Burdett Coutts these lignite-beds were minutely investigated by Mr. Pengelly, and the plant-remains collected under his superintendence were submitted for determination to Dr. Oswald Heer, who pronounced them to be undoubtedly Miocene. Lyell places the beds in the Lower Miocene division, as also the Hempstead Beds.

BOVEY BEDS.

The celebrated clays and lignite-beds of Bovey Tracey have been long known, for the 'Bovey Coal' has probably been worked for the last 150 years.

[1] Sometimes spelt Meiocene.

The Bovey Beds comprise two well-marked divisions, the lignite-beds which are developed at Bovey Tracey, and the clay-beds which are so largely worked near Kingsteignton and Newton Abbot.

The exact relations between these two divisions cannot readily be ascertained, for the lignite-beds are cut off by a fault (determined by Mr. Divett), where the vertical displacement is estimated at 100 feet; but so far as I could determine from personal examination the lignites form the upper series above the clays.

The beds opened up at Bovey (according to Mr. Pengelly) are as follows:—

	Feet	inches
'Head,' superficial drift	7	6
Plastic clay	2	6
Quartzose sand	6	3
Clays and lignites	5	11
Sand	2	0
Clay	2	0
Sand and fine conglomerate	0	8
Clays and lignites	33	10
Quartzose sand with lenticular patches of clay	11	1
Clay and lignites	53	4
	117	7

A boring made east of the fault showed upwards of 80 feet of sands and clays, with some coaly beds in the lower portion.

The clay-beds of Kingsteignton are about 40 feet in thickness, resting on sand, and containing occasional sandy beds.

The total thickness of the Bovey deposit can only be conjectured as between 200 and 300 feet.

The beds extend over a considerable tract of low-lying heath-land bounded by ranges of hills. The physical and palæontological evidence points to the deposit having been formed in a fresh-water lake, which probably extended from

Bovey Tracey to Kingskerswell, without being open towards Teignmouth. The purely sedimentary matter was evidently derived from the waste of the Greensand and of the granitic rocks of Dartmoor: the clays being due to the decomposition of the felspars, and the quartzose sands being the relics of the harder material. (See fig. 12, p. 110.)

It has been conjectured that the Lower Bagshot beds of Poole were similarly derived, and although there is great similarity in the general character of these beds and those of Bovey, yet it appears that the plant-remains of the two deposits are very distinct.

From Dr. Heer's investigations it seems that the woods covering the slopes which surrounded the old lake consisted mainly of a huge coniferous tree (*Sequoia Coutssiæ*), whose figure resembled in all probability its highly admired cousin, the *Sequoia* (*Wellingtonia*) *gigantea* of California. The leafy trees of most frequent occurrence were the cinnamons and an evergreen oak like those which now are seen in Mexico. Species of evergreen fig were rarer. The trees of the ancient forest were evidently festooned with vines, beside which the prickly Rotang-palm twined its snake-like form. In the shade of the forest throve numerous ferns; one species of *Pecopteris* seems to have formed trees of imposing grandeur, while on the surface of the lake were expanded leaves of the water-lily.[1]

The lignite, which has been used extensively for fuel, is very little employed now, as it gives off a sulphurous smell when burning.

The clay-beds yield excellent pipe and potters'-clay. The best clay is shipped at Teignmouth, whence it is sometimes termed 'Teignmouth Clay.' According to Mr. Hunt's Statistics above 42,000 tons were sent from the port of Teignmouth in 1865. The mode of raising the clay is extremely

[1] *Phil. Trans.*, Part II. 1862.

simple—the gravel head is removed, and a large rectangular pit is sunk, which is supported by wood. The workmen cut out the clay in cubical lumps weighing about 30 lbs. each, and fling them from stage to stage by means of a pointed staff; it is then carried to the clay cellars, and when properly dried sent to the potters.

Iron-pyrites is abundant in the lignite-beds, and from its presence spontaneous combustion sometimes takes place after heavy rain in the refuse-heaps.

The clays are employed for whitening stones, &c.; they have also been used in the manufacture of alum.

PLIOCENE.[1]

The Pliocene deposits of England, so far as known, occur in the Eastern Counties, and are recognized not only by position, but by the large per-centage of recent species of Mollusca which they contain. Their exact relations, however, to the Miocene period are not by any means definite, and some authorities have classed the lowermost division of the series—the Coralline Crag—as Miocene; but this seems to be an unnecessary complication in classification, and certainly the Crag deposits are closely united as well in their physical as in their palæontological characters.

Certain ferruginous sands containing casts of molluscs which occur on the Chalk in Kent and Surrey, were at one time considered as Crag, but their age is extremely doubtful, and it is uncertain whether they all belong to one period. (See p. 264.)

Some of the pebbly gravels which cap the Tertiary hills

[1] Sometimes spelt Pleiocene. The term Icenian was proposed for the Pliocene strata, because their order of succession was first determined in the Eastern Counties. (S. P. Woodward.)

in Hertfordshire and elsewhere may, as suggested by Prof. Hughes, be of Pliocene age, but this view depends very much upon the position of the boundary-line taken between Pliocene and Glacial deposits. (See p. 312.)

CRAG.

The deposits of shelly sand called 'Crag' which occur on the eastern borders of Norfolk, Suffolk, and Essex, have long been known, but for the minute description and identification of their Molluscan remains we are indebted to Mr. Searles Wood, sen., while we owe our knowledge of the detailed structure of the deposits very largely to Mr. Wood, jun.

Forty years ago, however (1835), Mr. Charlesworth gave the first good account of the Crags in Suffolk, and he then proposed the terms 'Red Crag' and 'Coralline Crag' to distinguish them from one another, and from the Norfolk or Norwich Crag, to which he subsequently applied the term 'Mammaliferous Crag.'

Since this date the labours of Messrs. S. V. Wood, jun., F. W. Harmer, the Rev. O. Fisher, Prestwich, and some others, have added greatly to our knowledge of the Pliocene strata, and the following stratigraphical divisions are now generally adopted—the upper part of the Red Crag being considered as the representative of the Fluvio-marine Crag :—

5. Bure Valley Beds.[1]	Norwich Crag or Laminated Series (*Newer Pliocene.*)
4. Chillesford Beds.	
3. Fluvio-marine Crag.	
2. Red Crag.	(*Older Pliocene.*)
1. Coralline Crag.	

[1] Classed as Lower Glacial by Wood and Harmer. (See p. 308.)

CORALLINE CRAG.

Suffolk Crag, White Crag, or Bryozoan Crag.[1]

The Coralline Crag consists of a series of calcareous shelly sands, sometimes marly, and having a thickness of from 40 to 60 feet.

The following general divisions are abbreviated from those given by Mr. Prestwich:—

7. Sand and comminuted shells, with remains of Bryozoa, sometimes forming a soft building-stone, showing much false-bedding.
6. Sand with small shells and seams of comminuted shell.
5. Sands with numerous Bryozoa, often in the original position of growth, and containing also small shells and Echini.
4. Comminuted shells, large entire or double shells, and bands of limestone.
3. Marly beds with well-preserved shells.
2. Comminuted shell-beds with Cetacean remains and Bryozoa.
1. Bed with Phosphatic nodules, called 'Coprolites,' and mammalian remains,—called the Suffolk Bone-bed.

The Suffolk bone-bed, or 'Coprolite bed,' has been described by Mr. E. Ray Lankester as being a bed from half a foot to three feet in thickness, and lying upon the London Clay in Suffolk wherever the Red Crag or the Coralline Crag is found. It is composed of rounded phosphatic nodules called 'coprolites,' and water-worn teeth and bones of Mastodon, Rhinoceros, Tapir, Bear, Whale, and Shark. Mr. Lankester considers that the Cetacean remains were derived from the older crag-deposit found in Belgium, and known as the Diestien or Black-crag.[2]

The beds at the base of the Red Crag may, however, have

[1] The term Bryozoan Crag was proposed, because there are few Corals in this Crag, the forms which led to the proposal of the term Coralline being Bryozoa or Polyzoa.

[2] Mr. Colchester considers the 'Coprolite' bed to be the débris of a bed intermediate in age between the London Clay and the Coralline Crag.

been derived from those formed at the time of the Coralline Crag. (See p. 285.)

In the Suffolk Bone-bed are found rounded masses and nodules of sandstone termed Box stones, which sometimes contain fossils. Mr. Lankester has remarked on their resemblance to the Lenham sandstones. (See p. 264.)

The Coralline Crag is well shown in the neighbourhood of Woodbridge, Aldborough, and Orford, at Sutton, Ramsholt, Sudbourne, Broom Hill, Gedgrave, &c.

Amongst the fossils are *Cypræa Europæa*, *Voluta Lamberti*, *Turritella incrassata*, *Fusus consocialis*, *F. gracilis*, *Scalaria clathratula*, *Natica*, *Calyptræa Chinensis*, *Fissurella Græca*, *Anomia ephippium*, *Ostrea edulis*, *Pecten opercularis*, *P. maximus*, *P. Gerardii*, *Pinna pectinata*, *Pectunculus glycimeris*, *Nucula nucleus*, *Lucina borealis*, *Diplodonta rotundata*, *Cardita senilis*, *C. scalaris*, *Astarte Omalii*, *A. gracilis*, *Cyprina Islandica*, *C. rustica*, *Venus casina*, *Panopæa Faujasii*, *Terebratula grandis*, *Balanus crenatus*, *Fascicularia*, *Cladocora*, *Turbinolia*, *Echinus Woodwardi*, *Heteropora pustulosa*, *Cellepora edax*, &c.

Mr. Wood considers that the Coralline Crag was deposited in the sea at no depth greater than 300 feet.

RED CRAG.

This deposit consists generally of dark red shelly sand, often exhibiting false-bedding or oblique lamination, and having a thickness of about 25 feet. Sometimes the colour is yellow, brown or grey. Seams of laminated clay are occasionally met with. Mr. S. V. Wood, jun., has, however, shown that the deposit is structurally divisible into five stages, of which the 1st, 2nd, 3rd, and 4th (counting upwards) were not deposited under water; but from their being regularly laminated, at angles varying between 25° and 35°, and possessing (with the exception of the 2nd) an unvarying direction

in every stage, he regards them as the result of a process of 'beaching up,' by which was formed a reef extending from the river Alde on the north, to the southern extremity of the deposit in Essex. Of these four stages, the 4th is the most constant and important, the 1st, 2nd, and 3rd being frequently either concealed by, or destroyed during the formation of, the succeeding stages. At Walton-on-Naze alone do any of the four lower stages contain evidence of being a subaqueous deposit; there the 1st stage is so, but it is covered by two reef stages, and these again by the 5th stage.

The 5th stage is invariably horizontal, and contains evidence of having been formed under water. This stage is developed in such a way as to show that it was formed in channels eroded in the older reef, and it is at its base that the coprolite workings occur.

Owing, however, to the probable reconstruction or re-accumulation of different stages, Mr. Wood considers it impossible to separate the Red Crag in general, into all those chronological divisions of it that may exist, but there are three divisions that are very clearly indicated:—

3. Scrobicularia Crag { Largely made up of *Tellina prætenuis*, and *T. obliqua*, with also *Scrobicularia plana*.
2. Deben, Orwell, and Butley Red Crag, with northern forms of mollusca predominating.
1. Walton Grey and Red Crag, containing many species characteristic of the Coralline Crag.

The Scrobicularia Crag comprises beds which gradually lose both the red colour and the oblique bedding as we ascend the section, and become horizontal in the upper layers.

The Red Crag is well shown at Walton-on-the-Naze, Sutton, Ramsholt, Trimley, Bawdsey, Butley, Hollesley, &c.

Near Aldborough and at Park Farm, Tattingstone near Ipswich, the Red Crag may be seen in section superimposed upon the Coralline Crag.

A bed of phosphatic nodules called 'coprolites' often occurs at the base of the Red Crag, and with it are found fragments of septaria from the London Clay, Chalk flints, Greensand chert, rolled or water-worn bones and teeth of Cetacea, Sharks (*Carcharodon megalodon*), &c. According to Mr. Prestwich seams of phosphatic nodules, or dispersed nodules, may be found through the whole of the Red Crag; and all of them were probably derived from the Coralline Crag. Among the Cetacean bones are the earbones of Whales, while other derived fossils are Crustacea from the London Clay.[1]

The 'coprolites' yield from 45 to 60 per cent. of Phosphate of Lime: they have been worked near Sutton, Boyton, Butley, Trimley, Bawdsey, Shottisham, &c. The beds are however becoming exhausted. (See p. 244.)

The question whether some of the forms characteristic of the Coralline Crag may not be derived from older deposits, is important, but, according to Mr. Wood, it is a still more complicated problem whether or not the fossils of the Red Crag in its various stages have a derived origin.

The fossils of the Red Crag include the *Trophon* (*Fusus*) *antiquum*, of which the sinistral or left-sided form (var. *contrarium*), according to Mr. Wood, is found in the Walton Crag, while the dextral form abounds in the rest of the Red Crag. Other fossils are *Pecten opercularis*, *Pectunculus glycimeris*, *Mactra arcuata*, *M. ovalis*, *Tellina obliqua*, *Cardium edule*, *C. angustatum*, *Mytilus edulis*, *Nassa reticosa*, *Buccinum tenerum*, *B. undatum*, *Natica catena*, *N. multipunctata*, *Purpura tetragona*, *P. lapillus*, *Turritella incrassata*, &c.

In the famous sections at Chillesford the Scrobicularia Crag rests upon the Red Crag (of Butley), and is directly

[1] Many fossil bones and teeth washed out of the Red Crag may be picked up on the beach at Harwich and Walton.

overlaid by the Chillesford Beds. It was these sections, first noticed by Mr. Prestwich, which led to the relations of the Norwich (Fluvio-marine) Crag and Red Crag being determined—the former being the equivalent of the higher portion of the latter. (See p. 289.)

From a careful study of the Crag district Mr. S. V. Wood, jun., concludes that the *northern* part of the Red Crag area continued to receive accumulations up to and during the time when the Fluvio-marine Crag was deposited; these beds were overlaid conformably by the Chillesford Beds, while in the southern part of the Red Crag area, as at Walton-on-the-Naze, the Chillesford Beds overlapped and rested unconformably upon the lower portion of the Red Crag.

NORWICH CRAG SERIES.

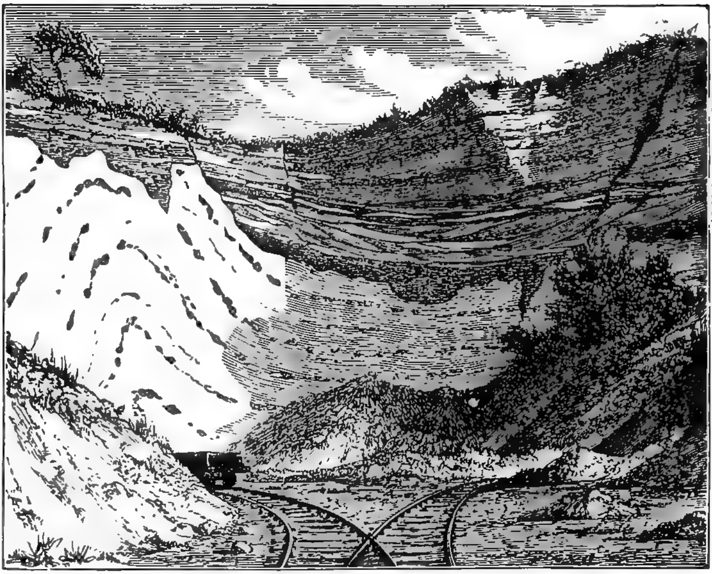
Laminated Series. (Gunn.)

The seams of shelly sand or crag which occur in Norfolk are of a very impersistent character, but the researches of the Messrs. Wood, of Mr. F. W. Harmer, and of Mr. J. E. Taylor, have demonstrated that there are at least three horizons of crag which are termed the Fluvio-marine Crag or Norwich Crag proper, the Chillesford Crag, and the Bure Valley Crag; and that these are marked by some differences in the assemblage of mollusca.

The formation, to which the term 'Norwich Crag series' seems applicable, comprises a variable set of beds, of sands, laminated clays, and shingle, with in places seams of shells, which rest on the Chalk, attain a thickness of about 30 feet, and are overlaid by the Glacial deposits.

[In this section No. 5 is the representative of the Bure Valley Beds, No. 4 embraces the Chillesford Beds, and Nos. 2 and 3 include the Fluvio-marine Crag. The beds are very variable, and attain a total thickness of about 20 feet. The disturbance in the Chalk so conspicuous in 1868, is not very marked in the portions of Chalk now exposed (1876).]

FIG. 21.—*Chalk pit at Whitlingham, near Norwich.*



5. Pebbly gravel and sand.
4. Laminated clay and shelly seam.
3. Sand and gravel, false-bedded.
2. Shell-bed and large flints.
1. Chalk (disturbed).

Fluvio-marine Crag.[1]

The Fluvio-marine Crag consists of buff-coloured shelly sands and shingle, often false-bedded, having a thickness of

[1] This is by no means a good name, as the Chillesford Beds are in places fluvio-marine, and the Bure Valley Beds contain some freshwater molluscs.

5 or 10 feet, and containing an admixture of marine and freshwater mollusca. It is probably of the same age as the upper part of the Red Crag, as both deposits in places are overlaid conformably by the Chillesford Beds.

Mr. J. E. Taylor first drew prominent attention to the fact that at Bramerton, where two layers of Crag are to be seen, the upper division contained shells of a more northern or arctic character than the lower one; and this Upper Crag (or 'Taylor's Bed') was identified by the Messrs. Wood with the shell-bed above the Red Crag at Chillesford.

At the base of the Fluvio-marine Crag is a bed termed by Mr. John Gunn the 'Stone bed.' It rests on the Chalk the surface of which is occasionally bored by Pholas, and much furrowed and eroded. This bed yields numerous Mammalian remains, including *Mastodon Arvernensis*, *Elephas meridionalis*, *Hippopotamus major*, *Rhinoceros leptorhinus*, *Cervus*, *Equus*, *Bos*, *Trogontherium Cuvieri*, &c.[1]

The Fluvio-marine Crag beds are well shown at Thorpe, Postwick, and Bramerton near Norwich, at Bulchamp, Wangford (10 feet), and Thorpe near Aldborough in Suffolk; they have also been exposed at Bungay, as Mr. C. Reid has determined.

Among the common fossils are *Tellina obliqua*, *T. lata*, *T. prætenuis*, *Cardium edule*, *Mytilus edulis*, *Mactra* (several species), *Litorina litorea*, *Conovulus pyramidalis*, *Purpura lapillus*, *Trophon scalariforme*, *T. antiquum*, *Turritella communis*, *Cerithium punctatum*, *Paludina media*, *Hydrobia ventrosa*, *Balanus crenatus*, Fish-remains, &c. *Scrobicularia plana* occurs at Bramerton.

Jet and Beekite are occasionally met with in the Fluvio-marine Crag.

[1] Mr. Charlesworth gave the name Mammaliferous Crag to the entire series of beds, but it is now known, through the researches of Mr. Gunn, that the remains belong properly to the basement- or stone-bed, and that when found higher up in the series they show signs of being derived.

Chillesford Beds.

The Chillesford Beds (so named from Chillesford near Orford, in Suffolk) are subdivided by Mr. Wood, jun., into :—

2. Chillesford Clay.
1. Chillesford Sand with Shell-bed.

The Chillesford Sand consists of micaceous sand with a shelly bed (not constant); this passes upwards into a bed of laminated micaceous clay, containing a few shells—the Chillesford Clay. The entire thickness is from 20 to 25 feet.

The fossils include *Astarte borealis*, *Tellina obliqua*, *T. lata*, *T. prætenuis*, *Cardium edule*, *Cyprina Islandica*, *Nucula Cobboldiæ*, *Mactra ovalis*, *Mya truncata* (= Mya bed of the Rev. O. Fisher), *Purpura crispata*, *Litorina litorea*.

Mr. Wood observes that the Chillesford Clay varies from a dark blue tenacious laminated clay, as at Aldeby and Easton Cliff, to a loamy micaceous sand, more or less interbedded with seams of laminated clay, as on the immediate west of Beccles, and on the south of Norwich, but it is easily recognizable everywhere.

In the pit at Bramerton, near Norwich, the following beds are seen resting upon the Chalk :—

		Feet
Chillesford Beds	Chillesford Clay	1
	Chillesford Sand with Shell-bed .	5
Fluvio-marine Crag	Unfossiliferous Sand	12
	Fluvio-marine Crag	5

Between the Fluvio-marine Crag and Chillesford Beds at this locality is a layer of unfossiliferous sand about 12 feet in thickness, which Mr. Wood considers as equivalent to the Scrobicularia Crag of the Chillesford Section, which is as follows :—

		Feet
Chillesford Beds	Chillesford Clay	8
	Chillesford Sand with Shell-bed .	8
Red Crag . .	Scrobicularia Crag	10
	Red Crag	10

At Bramerton and Chillesford the Chillesford Beds, according to Mr. Wood, are marine; while at Easton Bavent, Burgh Kiln (near Aylsham), Coltishall, Horstead, Aldeby[1] (Toft Monks), the Chillesford Beds are fluvio-marine in character.

The Chillesford Beds are overlaid by the Bure Valley Beds, which form a connecting link between the Pliocene and Glacial series.

Bure Valley Beds.

Westleton Beds—(Prestwich).

These beds—the pebbly sands and pebble-beds—have been elucidated and described by Messrs. S. V. Wood, jun., and F. W. Harmer. The sands are mostly of a deep orange colour, and in them are seams and beds of rolled pebbles, which sometimes so predominate as to form masses of shingle: seams of laminated clay are not uncommon.

Near Halesworth and Henham they are described as forming true beaches, and at the latter place they attain a thickness of 25 feet.

The base of the Sands, when resting on the Chalk, is often occupied by an accumulation of shell-patches, known as Crag (*Tellina-Balthica* Crag): recognizable forms occur at Crostwick, Rackheath, Spixworth, Wroxham, Belaugh, Weybourn, Runton, and Trimmingham.

According to Messrs. Wood and Harmer they form the base of the whole Glacial series, and indicate the first setting

[1] The fossils of the Aldeby Beds have been most carefully worked out by Messrs. W. M. Crowfoot and E. T. Dowson.

in of the great Glacial subsidence. They consider them to be unconformable to the Chillesford Beds, because in certain places along the Bure Valley and near Halesworth, the Chillesford Beds have been denuded prior to their accumulation. They are characterized by the first appearance in England of *Tellina Balthica* (*solidula*). The other fossils include *Tellina obliqua*, *Cyprina Islandica*, *Leda oblongoides*, *Cardium edule*, *Litorina litorea*, &c.

These beds range from the Bure Valley past Norwich to the neighbourhood of Southwold, and expand northwards into the Weybourn sand. In the Norfolk Cliffs they form a very variable series.

East of Cromer the sand becomes charged with lignite, and often laminated with bands of lignitiferous clay, in which condition it constitutes the 'Laminated beds' of Mr. John Gunn.[1] It passes up in places by interbedding into the Cromer Till.

In some localities near Norwich there is no definite line of separation between the Bure Valley Beds and the Chillesford Beds, and Fluvio-marine Crag beneath; and moreover they seem all of them to be so closely connected in their derivation and method of accumulation, that I prefer classing them together as one group—the Norwich Crag series.

FOREST BED SERIES.

One of the most remarkable deposits with which we are acquainted is the so-called Forest Bed of Cromer on the

[1] Mr. Gunn considers these Laminated beds to represent the Chillesford Clay; he, however, uses the term Laminated series as a comprehensive term for all the strata from the Fluvio-marine Crag to the base of the Glacial series, and in the same sense as the term Norwich Crag Series is here used.

Norfolk Coast. This bed, so noted for the Mammalian remains which it has yielded, maintains a remarkable persistence wherever it has been observed, at about the same level, along the shore or fore-shore between Runton in Norfolk and Kessingland in Suffolk.

The Forest Bed occurs at the base of the Glacial series, and beneath the pebbly sands and the laminated beds (=Bure Valley Beds). But its precise relations to the lower portion of the Norwich Crag Series have not been determined. Its junction with the Chalk has never been observed, and therefore the total thickness of the series is unknown.

Its persistence thus along the coast is all the more remarkable if, as Lyell considered, there must have been a subsidence of the forest to the amount of 400 or 500 feet, and a re-elevation of the same to an equal extent, in order to allow the ancient surface of the Chalk with its covering of soil, on which the forest grew, to be first covered with several hundred feet of drift.

As the Forest Bed is intimately associated with several other beds of local interest, the term Forest Bed Series seems most applicable to these deposits.

To the indefatigable researches of Mr. John Gunn we chiefly owe our knowledge of the physical geography and the very interesting fauna and flora of the period when these beds were deposited. Some of his remarks I now quote.

'The soil of the Forest Bed appears to consist of an argillaceous sand and gravel (pan), or a compound of both, and to have been deposited in an estuary. Bones of *Elephas meridionalis*, together with a great variety of deer and other mammals, sharply fractured, but not rolled, are found in it, especially in the gravel, which is called the "Elephant-bed" on that account. These are associated with the bones of whales and fragments of wood, indicating that the Estuary

was open to the sea, most probably northwards, for the admission of the whales; while it appears to have been closed at the Straits of Dover and Calais, to afford a passage for the mammals into this country. This deposit of the soil may be regarded as the first phase of the Forest Bed; and here, we may observe, a long interval may have intervened between this and the second phase, which dates from the raising of the soil to the surface of the waters and the growth of the forest upon it. In this the remains of the *E. antiquus* are most abundant; other varieties of the Elephant are found here, together with *Rhinoceros etruscus* and *Trogontherium Cuvieri*. This may be regarded as the true Forest Bed; the stools of the trees belonging to it are visible along the coast at various places from Kessingland to Cromer.' (Gunn.)

A black freshwater peaty clay, with *Unio*, &c., and a 'rootlet-bed' occur above the Forest Bed at Runton, Kessingland, &c.

Blue clay and gravel indurated into 'pan' may be traced at intervals along the coast near Overstrand Gap, Mundesley, Trimmingham, and Cromer. At Bacton the clay is of a greenish colour.

Those who wish to examine the Forest Bed of Cromer may be disappointed in not being able to determine its exact relations to the Glacial beds in the cliff-sections, for seldom save at low tide can the Forest bed be seen at all, and it is only at a few places that it has been seen *in situ* beneath the Glacial beds, owing to the recent deposits of sand and shingle that are banked up against the cliffs.

Through the Forest Bed are scattered cones of the Scotch and spruce firs with the seeds of recent plants, and the bones of at least twenty species of terrestrial mammalia. These mammalian remains occur chiefly in the pan, and include

Elephas meridionalis, *E. antiquus*, *Hippopotamus major*, *Rhinoceros etruscus*, *Bison priscus*, *Cervus* (several species), *Trogontherium Cuvieri* (a gigantic Beaver), &c.

We are greatly indebted to Mr. John Gunn for the large collection of these remains placed in the Norwich Museum, and to the late Rev. S. W. King for a collection now in the Museum at Jermyn Street.[1]

Messrs. Wood and Harmer consider that with the exception of certain cetacean vertebræ found in the Chillesford Clay at Chillesford, it is open to question whether any of the Mammalian remains obtained from the Fluvio-marine Crag, or from the Chillesford beds, belonged to individuals which lived during the accumulation of these deposits. The Mastodon teeth found in the Red and Fluvio-marine Crags, and in the Chillesford Beds, have, they think, been derived from destroyed freshwater deposits intermediate between the Coralline Crag and the Red Crag. From the fact that no trace of the Mastodon has yet been found among the abundant elephantine remains from the Forest Bed, they consider it doubtful whether that animal lived during the age of the Chillesford Crag; since the Forest Bed, if it be not actually coeval with this deposit containing Mastodon remains, is evidently separated from the latest of them by an interval of time too slight (and accompanied apparently by no change of climate) satisfactorily to account for the disappearance of this great proboscidean genus.

Thus, while there is no evidence to show that the Forest Bed Series, with its estuarine soil, its land surface, and subse-

[1] A great number of Mammalian remains have been dredged off the coast; according to Mr. S. Woodward, the Oyster Ridge off Happisburgh and the Knole Sand off Yarmouth have contributed most largely. He mentioned that at one time the Rev. James Layton of Catfield had as many as 600 grinders of the Elephant! Most of these remains, however, belong to a Post-Glacial deposit, and not to the Forest Bed.

quent freshwater deposits, may not have been accumulated (at any rate in part) contemporaneously with the deposition of the Fluvio-marine Crag, its exact relation to the Chillesford Beds is a matter of dispute, but there is no question whatever that subsequent depression allowed the Bure Valley Beds to extend over a larger area than that occupied by the Fluvio-marine Crag and Chillesford Beds, and to rest in places directly upon the Forest Bed Series.

SECTION IV.

QUATERNARY OR POST-TERTIARY.

Chapter X.

POST-PLIOCENE OR PLEISTOCENE.

In considering the deposits of Post-Pliocene date that occur in different parts of England and Wales, one is immediately struck with their wide range and extensive distribution as compared with the other and older strata. These deposits, known under the familiar name of Drift, have but lately received their due acknowledgment and rank as geological formations, being in many publications treated as superficial deposits, and as apparently belonging to quite another order of creation to the more 'solid' rocks that underlie them. As these Drift deposits rival and even exceed in thickness some formations in our geological tables, and as, taken collectively, they have a more direct influence upon Agriculture than any other formation, their importance may be readily conceded. But I am well aware that in most cases it would be exceedingly difficult, if not impossible, to show these Drifts with any approach to accuracy on a map smaller than that of the one-inch Ordnance Survey, and upon that they are now represented by the Geological Survey of England and Wales. Moreover, the Drifts themselves play a comparatively insignificant part in the formation of our scenery, for the great features that our country now possesses were nearly all marked out before the Drifts were deposited.

The word 'Diluvium' was originally applied to deposits supposed to have been formed or deposited during violent water action, such as would take place in periods of excessive rain-fall, causing torrents of water in the rivers, floods or deluges, or by the sea or rivers bursting through some bank or sea-wall. It is a term now little used, owing to the deposits termed Diluvial being frequently misunderstood to indicate a Universal Deluge. The term 'Drift' is generally synonymous, and would naturally refer to beds formed from rocks at a distance from the localities where they have been deposited. 'For instance'—to quote Conybeare (1822)—'when we find rounded pebbles derived from rocks which exist *in situ* only in the mountains of the north and west, scattered over the plains of the midland counties, we may be sure that the currents drifted from the former point to the latter; and it often affords a curious and interesting problem to the geologist to trace these travelled fragments to their native masses, often hundreds of miles distant. The accumulations of this gravel above referred to, in the midland counties, especially along the plains at the foot of the escarpment of the chain of the Inferior Oolite on the borders of Gloucestershire, Northamptonshire, and Warwickshire, are of surprising extent, and the materials brought together are from so many quarters, that it would not be difficult to form a nearly complete suite of the geological formations of England from their fragments here deposited. Portions of the same gravel have been swept onwards through transverse valleys affording openings across the chains of Oolite and Chalk hills, as far as the plains surrounding the metropolis; but the principal mass of the diluvial gravel in this latter quarter is derived from the partial destruction of the neighbouring Chalk hills, consisting of flints washed out from thence, and subsequently rounded by attrition.'

In considering the relations of the different Drift deposits

we enter upon a subject of great difficulty, and yet, perhaps, during the past ten or fifteen years no subject has received greater attention than the elucidation of their method of formation and respective ages.

The Drifts include deposits of loam, sand, gravel, and clay; they occur at all levels; some clearly owe their origin to the action of our present rivers, some to the agency of the sea, and some to glaciers, ice-sheets, and icebergs: some also indicate a combination of two or more of these agencies in their formation, dispersion, and accumulation.

That the Pliocene Period was succeeded by one of intense cold has been fully proved; the changes of temperature were gradual, but at the same time, looked at in a large way, this cold period can be well defined, and the deposits belonging to it are considered as of Glacial age. Thus, in speaking of Glacial deposits, it must be remembered that the term refers rather to age and climate than to method of formation.

It must be borne in mind, however, that this Glacial Period, or 'Great Ice Age,' was not *necessarily* the most important Glacial period that has occurred during geological times. Mr. Croll has stated his opinion that these periods of intense cold were periodical: we have indications of transport by ice agency in the Chalk period; and in Permian times, as Prof. Ramsay has shown, we have true Glacial deposits. The deposits, however, that evidence the Post-Pliocene Glacial period are the most extensive of the kind, and their preservation is due in a great measure to the fact that Post-Glacial changes have not been of sufficient magnitude to allow denudation to obliterate them. The same may be said of the extensive river-gravels and brickearths.

Mr. James Geikie has well observed that, even now, the action of the weather, of frost, rain, and rivers, is slowly but surely effacing the marks left by the old glaciers. And should our islands eventually become submerged, it might

well be that, as the land sank down, what the atmospheric forces had failed to obliterate would succumb to the action of the sea; and should the land be afterwards re-elevated, it is very doubtful indeed whether a single recognizable trace of former Glacial work would remain.

In the following pages I shall, after describing the nature of the deposits, only indicate their distribution in a very general manner.

Some of the Drift deposits may indeed be of earlier age than the Glacial period, for if we believe that a considerable mass of the Chalk, which must have covered the greater part of England and probably the whole of Wales, was removed by marine denudation, and some of the Tertiary beds are made up entirely of flint pebbles, it is not impossible that some of the plateau-gravels whose age is as yet undetermined, may be due in part to marine denudation of the Chalk in Tertiary times. Moreover, the deposit called Clay-with-flints may be of all ages subsequent to the consolidation of the Chalk and its elevation to form a land area.

The Quaternary phenomena and deposits may be roughly classed as follows:[1]—

Sub-aërial.—Soils, Peat, Submarine Forests, Caverns and Cavern-deposits, Springs and Tufa, Blown Sand, &c.

Fluviatile and Lacustrine.—Valley Gravels and Brickearth.

Marine.—Raised Beaches, Burtle Beds, Shingle-beaches, &c.

Glacial.—Boulder Clay, Gravel, &c.

In the present state of our knowledge, it is quite impossible to classify these various deposits exactly according to their relative ages. Some Caverns may be exceedingly old; in fact, their formation might commence soon after the consolidation of the rocks in which they have been excavated. The deposits met with in them may, so far as the physical evidence is concerned, be of many very different ages.

[1] This is only given as a very general classification.

Some of our valley-deposits may (it has been conjectured) be Pre-Glacial, but it will be sufficient to indicate this opinion without attempting to classify the gravels and brickearths formed by different rivers.

There is no question, however, about the antiquity and relative position of most of the deposits of Glacial age, and of these we may first treat.

In places it is difficult to distinguish between glacial gravels and river gravels.

'Considerable accumulations of fluviatile gravel occur in the valleys, often at great heights above the present rivers. This gravel, when traced up stream, becomes coarser and earthier, and not a few of the stones even show faint traces of striæ. As we follow it still farther into the mountains, it appears to pass into, or at least it cannot be distinguished from, moraine débris. Opposite the mouths of some of the mountain valleys, great deposits of hummocky angular and sub-angular gravel make their appearance.' (J. Geikie.)

GLACIAL PERIOD.

The Glacial period, so called, has itself been marked by many changes, the duration of which geologists can only speculate upon.

Upwards of 200,000 years ago the earth (says Mr. James Geikie), as we know from the calculations of astronomers, was so placed in regard to the sun that a series of physical changes was induced, which eventually resulted in conferring upon our hemisphere a most intensely severe climate. But the observations of geologists, comparing the past with the present, had many years ago led them to infer such a period of cold.

In the mountainous districts the direct action of former

glaciers may be traced; *Blocs perchés* are found in most valleys in the Lake District and North Wales, while grooved and polished rock-surfaces and striated stones have been detected in many places. In some of the low-lands are deposits of distant origin which cannot have been accumulated by rain and rivers, nor have been formed unaided by marine action.

In 1831 Mr. J. Trimmer detected traces of stratified drift containing marine shells at a height of 1,300 feet on Moel Tryfaen, which indicated a submergence to this extent in Post-Pliocene times; and in 1842 Dr. Buckland recognized the former existence of glaciers in many parts of North Wales.

Since this period the subject has been very extensively studied, and the general conclusions may be stated to be, that during what is called the Glacial period the northern parts of England and Wales were covered with ice;—(to quote Prof. Ramsay) 'the average level of the land may then have been higher than at present, by elevation of the whole, and a little because it had not suffered so much degradation: but whether this was so or not, the mountains and much of the low-lands were covered with a universal coating of ice, probably as thick as that in the north of Greenland in the present day.' Small glaciers were locally formed on the Snowdonian and Cumbrian hills. 'During the time that these great results were being produced by glacial action, there were occasional important oscillations in temperature, so that the ice sometimes increased and sometimes diminished, and land animals that lived habitually in more temperate regions, at intervals advanced north or retreated south with the retreating or advancing ice. At length, however, a slow submersion of the land took place.'

During the time when the lands in North Wales and the north of England were covered with ice, it has been conjectured

that the southern tracts of Wales and England were submerged, and then material extruded by the glaciers was dispersed over the submerged country, while ice-bergs may have given their contributions to the drifts that are scattered over the country. The subsequent period of greater submergence, which in Wales was more than 1,300 feet, was attended by the dispersion and deposition of more material.

Again the land rose, and glaciers were formed in North Wales and in the Lake District. Those who visit North Wales should carry Prof. Ramsay's 'Old Glaciers of Switzerland and North Wales' in their pockets. With this guide the many obvious facts will be understood even by those who have never seen a glacier—the old records of glacial action are as certainly marked on the rocks and in the valleys, as is the hand of man in the hieroglyphics on ancient monuments.

This is but a feeble sketch of the great changes indicated during the Glacial period, but it would be impossible here to do justice in so small a space as must be allotted to the subject, and those who would pursue the subject further should consult Mr. James Geikie's 'Great Ice Age.'

It may, however, be useful to give the following summary by Mr. Geikie of the great changes that occurred over the British Islands in the Quaternary period:[1]—

1. Indications of approaching cold are met with in the Newer Pliocene deposits.
2. Intense glacial conditions, with great confluent glaciers; intermediate mild, and warm periods; arctic and southern mammalia visit Britain alternately, according as climatal conditions become suited to their needs.
3. Disappearance of arctic conditions. Britain continental, with climate changing from cold to temperate and genial, and again to temperate. In early stages of continental conditions the arctic mammalia invade Britain; subsequently these disappear, and are succeeded by the hippopotamus, and other southern forms.

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[1] This Summary, which has been kindly furnished to me by Mr. Geikie, represents the views which are set forth in the New Edition of his work.

4. Gradual submergence of the land to a depth in Wales of not less than 1,400 feet. Depression probably partial and dying out rapidly towards the south. Climate temperate, but passing to cold-temperate, and to arctic in Scotland.
5. Gradual re-elevation of the land. Snowfields and glaciers increase until for the last time all Scotland, Wales, and the northern districts of England are covered with an ice-sheet.
6. Retreat of the ice. Great floods from the melting ice distribute vast quantities of gravel and sand over the low grounds.
7. Period of great local glaciers. Land of less extent than now. Floating ice. Climate arctic.
8. Britain becomes continental. Summer and winter temperatures more excessive than now. Age of great forests.
9. Final insulation of Britain. Climate humid. Decay of the forests and accumulation of peat-mosses. Land of less extent than now.
10. Partial re-elevation; climate temperate; the Present.[1]

This summary will be sufficient to indicate the great changes that have taken place since Pliocene times, changes which have not only modified the life-history of different tracts, but likewise the character of the sediments, rendering the minute examination of the various superficial deposits a matter of the greatest interest. And yet as they are more minutely divided in different localities, we find a greater difficulty in classifying them according to time, than is experienced in the larger divisions of the older stratified rocks.

Glacial Deposits.

The Glacial deposits, or rather the deposits of Glacial age, include various gravels, sands, loams, and clays. The term 'Boulder Clay' is applied essentially to the deposits of a clayey or loamy nature which contain large boulders of rocks many of which have frequently been brought from a distance, but Boulder Clay may at times contain very few large boulders, and at others be almost entirely made up of

[1] The effects of glacial action and the direction of the old ice-sheets in the north of England and Wales have been treated of by Tiddeman, Clifton Ward, Mackintosh, Goodchild, De Rance, and others.

them. In many parts of the Eastern Counties it is to a large extent made up of Chalk.

The term 'Till' was first applied in Scotland to the stiff unstratified clays containing angular, subangular, and rounded blocks of rock usually polished and striated, and is often used as synonymous for Boulder Clay: the former term is, however, sometimes restricted to the product of land ice, or of an ice-sheet, the latter to the same material when re-assorted or washed away and redeposited by marine action assisted by icebergs.

The term 'erratic' is applied to boulders that have travelled long distances from the parent rocks.

In Northumberland and in Holy Island beds of Boulder Clay and gravel have been detected; and in this county and in Durham, according to Prof. Ramsay, the miners, while mining a bed of coal, sometimes find the seam crop out deep underground, against a mass of boulder clay that fills an ancient rocky valley of which the plain above gives no indication.

The distribution of the granitic boulders from Criffel, Eskdale, and Shap Fell (Wastdale Crag), forms an interesting subject.

Wastdale Crag (to quote Dr. Nicholson) has been long known as affording most convincing proofs of the action of glaciers and icebergs in the north of England. The Crag itself is much smoothed and polished, or *moutonnéed*, and in some places is scored by glacial striations, which have a W.S.W. and E.N.E. direction. The erratic blocks are distributed in great numbers over the country to the south and east of the Crag for great distances: they have been traced over the Pennine chain to the Pass of Stainmoor (1,500 feet) as far as the eastern seaboard of Yorkshire.

Speaking of the Till in North Lancashire, which is the product of an ice-sheet, Mr. Tiddeman has observed that there is abundant evidence that it is not coloured by the rocks

on which it lies, but by the rocks over which it has been pushed; and that it is quite possible, nay certain, that in some areas there may be Till of totally different appearance, colour, and material, deposited side by side, by the same agents, and under the same conditions, at the same time.

In the neighbourhood of Manchester the researches of Messrs. Binney, Hull, and others have shown that the Drift deposits may be divided thus:—

Upper Boulder Clay.	Reddish-brown clay with glaciated pebbles and boulders, sometimes containing bands of sand, and showing more or less distinct traces of stratification.
Middle Sand and Gravel.	Fine sands, or gravel composed of waterworn pebbles, the whole distinctly stratified.
Lower Boulder Clay.	Reddish-brown stiff clay with glaciated pebbles, presenting faint traces of stratification.

All these divisions contain marine shells. (See p. 319.)

The thickness of these deposits is sometimes 150 or even 200 feet.

The Boulder Clay contains blocks of granite, syenite, porphyry, slate, &c.[1]

In the Isle of Man Mr. J. Horne has described the following beds:—

Boulder Clay, containing some scratched stones and angular boulders, 6 to 8 feet.

Sands and Gravels, finely stratified with many foreign rocks, evidently a marine deposit, 8 to 10 feet.

Bluish clay, very tough, containing scratched stones, but no large boulders, about 12 feet in thickness: this is the representative of the Scotch Till, and a product of land-ice.

These beds are well exposed about half a mile south of Ramsey, and they are overlaid (to quote Mr. Horne) by a series of well-stratified sands and gravels, which evidently

[1] Mr. Mackintosh mentions that in the eastern part of North Wales the boulders are called 'Granite tumblers,' and in Cheshire 'Marble stones.'

rest on an eroded surface of the boulder clay, and pass upwards into that great series of sands, gravels, and shelly clays which form the cliff from Ramsey to the Point of Ayre. The shelly clays contain marine molluscs. Some of the gravels belong to the Kame series.[1]

In North Wales there are many scattered drifts: near Llandudno Mr. G. Maw has noticed pockets of chert, white sand, and white clay in the Mountain Limestone; these he thinks may be Pre-Glacial deposits. Mr. Mackintosh has described similar beds near Mold. At Colwyn (Rhos) Bay, and in the Peninsula of Wirral, he has noticed the threefold division of the Drift, which has been made out in Lancashire. At Colwyn the beds are underlaid by a blue clay containing striated stones, which Mr. Mackintosh has traced in places through the West Riding of Yorkshire and Cumberland. He has also described many Eskers in North Wales, Cheshire and Shropshire.

In the drift of Warwickshire, according to the Rev. P. B. Brodie, are boulders of sandstone, quartz pebbles, Chalk and flints, Oolites, Lias, Carboniferous Limestone, pebbles of Lower Silurian [or Cambrian] age containing some remarkable fossils identical with those which occur in similar pebbles in the Trias at Budleigh Salterton in Devonshire.

In the Midland Counties, Nottinghamshire, Derbyshire, Warwickshire, Leicestershire, and Northamptonshire, there

[1] The term Kame is used in Scotland (Esker in Ireland and Åsar in Sweden) to denote certain peculiar ridges and mounds of drift which rest on the Boulder Clay and other Glacial Drifts, and regarding whose origin there has been much diversity of opinion. Some geologists maintain that they have been formed in the sea during submergence; others that they were produced by marine agency during the elevation of the area after submergence; some again consider that they are due to the action of subglacial waters (waters flowing underneath land-ice), or that they are morainic accumulations; while yet others have attributed them to torrential or fluviatile action.

are extensive deposits of Drift formed of rocks from many different formations, Chalk, Oolites, Lias, Coal Measures, Millstone Grit, Carboniferous Limestone, &c.

At Annesley, in Nottinghamshire, Mr. Aveline describes the gravel as sometimes cemented together into a breccia, and at Blidworth are some isolated masses popularly known as Druidical remains. These curious blocks were, no doubt, first roughly shaped out by the uncemented gravel having been denuded from around the cemented portions, leaving the latter standing high above the level of the ground. Some of these were afterwards shaped by men into their present forms.

In the Great Ponton cutting on the Great Northern Railway in Lincolnshire (to quote Professor Morris), 'we see the drift on either side of the cutting buoying up an enormous irregular mass of oolitic rock, through which the cutting has passed. This mass of rock is 430 feet long, and, at its deepest part, 30 feet thick; it is much broken and disturbed, but the parts retain to some extent their relative position, and belong to the lower portion of the Oolitic beds of the district.' He observes that although distinctly isolated, it retains sufficient uniformity of character to lead us to infer that it has not been far removed from its original site. This gigantic boulder is, however, not an isolated case, as other masses of Oolitic rock and Marlstone have been noticed in the district, sometimes of sufficient bulk to be quarried, while in the cliffs on the coast of Norfolk are large masses of Chalk which have been similarly drifted and re-deposited.[1]

[1] The following paragraph is taken from the work of Messrs. Conybeare and Phillips:—'In the fields on the south of Sywell in Northamptonshire, the fragments of Chalk are so abundant as to give the appearance of a regular substratum of that substance, turned up by the plough. In the Philosophical Transactions for 1701 is an account of a Chalk pit found at Redlington in Rutland; which, if correct, must be considered as

The drift-deposits of Yorkshire, Lincolnshire, and the Eastern Counties, have been most carefully investigated by Mr. S. V. Wood, jun., assisted by the Rev. J. L. Rome and Mr. F. W. Harmer. The following table exhibits their classification of the deposits:—

Older Post-Glacial.	Hessle (Boulder) Clay. Hessle gravel (Kelsea Hill bed). Nar valley beds. Gravels and brickearths [connected with the denudation of the Glacial beds during their emergence from the great depression].
Upper Glacial.	The purple (Boulder) clay of Yorkshire *without* chalk, passing down into The purple (Boulder) clay *with* chalk, and containing the Bridlington shell-bed. The great chalky (Boulder) clay.
Middle Glacial.	Sand, Gravel, and brickearth, with occasional seams of boulder clay.
Lower Glacial.	Contorted Drift. Cromer Till. Bure Valley Beds: see p. 290.

Prof. Phillips contended for the Pre-Glacial age of the Hessle Beds, but on the authority of Messrs. Wood and Rome they will here be treated of as Post-Glacial.

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a relic of this destroyed tract. The account is very precise, indicates a sufficient knowledge of the general nature and localities of the formation, and is such as to render the testimony very respectable; but the point is so important that further enquiries are desirable. The Chalk is described as regularly interstratified with flints; and the surrounding district being entirely occupied by the ferruginous sands of the Inferior Oolite, it is not easy to conceive that it could have afforded any rock which could have been mistaken for Chalk. Another detached patch of Chalk is said, in the same place, to exist near Stukely in Huntingdonshire on the banks of the Turnpike Road, but no particulars are given, and here soft varieties of other calcareous beds might be confounded with this substance.'

LOWER GLACIAL BEDS.

Lower Boulder Clay.

The Lower Glacial Beds are estimated to have a maximum thickness of about 200 feet.

In no other part of England and Wales are these Glacial Beds so well shown as in the cliffs along the Norfolk coast, which in places rise to a height of 200 feet.

Cromer Till.

The Cromer Till consists of a dark blue or grey sandy clay with numerous small pebbles of Chalk and other stones, and occasional large boulders of granitic rock, greenstone, and grit. Many of the stones show glacial striæ.

It generally rests upon the Bure Valley Beds, with which there appears in places to be some evidence of interstratification. It is not altogether persistent in the coast-section between Cromer and Happisburgh, but it forms a band that can readily be recognized. The junction with the beds above is not always very distinct; in some places there is a passage, in others there is evidence of local erosion, and the overlying beds occupy hollows on the surface of the Till. Inland it is inseparable from the Contorted Drift.

Contorted Drift.

This deposit consists essentially of a brown stony loam, sometimes well stratified and containing seams of gravel and sand, at others containing seams of chalky loam or boulder clay, and exhibiting most violent and remarkable contortions.

Messrs. Wood and Harmer have noticed its occurrence in Suffolk, as a reddish-brown brickearth, resting on the pebbly sands (Bure Valley Beds).

It is, however, in the cliffs between Eccles and Wey-

bourn that it can be best studied, and it there exhibits almost every variety of condition and contortion. The main portion of the cliffs is indeed made up of this usually brown loamy deposit, which rests on the blue Cromer Till. The contortions become conspicuous west of Mundesley, and thence near to Cromer, and between Cromer and Weybourn, seams of very chalky loam or boulder clay occur here and there in isolated irregular and lenticular masses. These are sometimes worked inland for lime.

Between East Runton and Woman Hythe are three large masses of transported Chalk which, by the weight of the bergs carrying them, have sunk in some cases into the subjacent Till, and even into the Weybourn Sand (Bure Valley Beds).

The Contorted Drift is extensively worked for bricks around Norwich, North Walsham, Aylsham, and many other parts of Norfolk: it is sometimes called the Norwich Brickearth. In Suffolk it has been observed at Somerleyton, Beccles, Harleston, Woolpit, Boxted, Sudbury, Kesgrave, Hasketon, &c.

Messrs. Wood and Harmer attribute the formation of the marly portion of the Contorted Drift to a discharge of ground-up Chalk from the *débouchure* of a Glacier that occupied the Chalk country of Cambridgeshire and West Suffolk; the brickearth which forms the easterly development of the Contorted Drift being due to a river discharge in that part; the two sediments intermingling in the intermediate area, and producing the alternations of marl and brickearth there presented by this formation. The detached masses of the marl were, they consider, introduced into the brickearth portion of the deposit by the agency of bergs, which, breaking from the Glacier and grounding, picked up masses of the marl forming over the sea-bottom in that part of the area. These masses the bergs carried out into the area where the brickearth was accumulating, and grounding again, imbedded them in the brickearth, and even in the subjacent Till and Weybourn Sand, contorting the beds in the process. From detached portions of this marl, which they have found as far south as Claydon, near Ipswich, and Stanstead, near Lavenham, in Suffolk, they infer that this deposit covered the West of Suffolk and Norfolk, but

underwent great denudation in the former part by the waters of the Middle Glacial sea, the sands of that sea, west and south of Diss, lying up to bosses of it in some parts, and overlying it in others.

The remarkable contortions of this Drift were well pictured by the late Mr. Samuel Woodward in his 'Geology of Norfolk.' The contortions have been attributed partly to the thawing of masses of ice which had been fixed among the beds during their deposition, but more generally to the action of stranding icebergs.

MIDDLE GLACIAL BEDS.

MIDDLE DRIFT.
BOULDER SANDS AND GRAVELS. (Prestwich.)

The Middle Glacial beds consist of gravel and sand with occasional beds or seams of chalky Boulder Clay, as near Hertford. The gravel is composed to a great extent of Chalk flints both subangular and rolled, and pebbles of quartz and quartzite. Its thickness is variable, being sometimes 15 or 20 feet, at others as much as 40 or even 70 feet. In some localities sand predominates, in others gravel, and occasionally a good deal of brickearth is associated with the beds. The sand sometimes contains pebbles of Chalk.

The gravel contains a great many rolled fossils derived from many different formations, but chiefly from those of Secondary age. The pits at Muswell Hill and Finchley, owing to the labours of Mr. N. T. Wetherell, have yielded a large number of specimens. (See fig. 22, p. 314.)

In some places in Essex the Middle Glacial gravel is very pebbly in nature, which in Mr. Wood's opinion was probably due to the proximity of Eocene pebble-beds, whether belonging to Reading Beds, London Clay, or Bagshot Beds.

In the neighbourhood of Hertford the Tertiary beds are capped by a pebbly gravel composed chiefly of flint and quartz pebbles. This is very distinct from the more mixed gravel on the Chalk, and has been termed by Prof. Hughes the 'gravel of the higher plain,' to distinguish it from that in the lower grounds. He suggested that it might be Pre-Glacial. It occurs also at Barnet, Totteridge, &c.

Along the borders of the Thames Valley it is often a matter of great difficulty to distinguish between the Middle Glacial gravels and those formed by the river in great measure from their destruction: such is the case near Great Marlow, also at intervals along the Valley as far as Southgate.

At Danbury, in Essex, the gravel occupies a high elevation, but the hill is coated with gravel and not formed by it, as Mr. W. H. Penning has traced the London Clay exposed in gullies near the hill-top.

Deposits of loam and brickearth are associated with the gravels on the Chalk tracts of Buckinghamshire and Hertfordshire, and sometimes with those on the London Clay; but it is not possible always to fix the ages of the deposit. Thus, at Chelmsford there is a deposit of brickearth, which may be of Glacial age or Post-Glacial.

Near Yarmouth, Messrs. S. V. Wood, jun., and Harmer have obtained from these Middle Glacial deposits shells of a southern aspect, including several extinct Crag forms, which tend to separate them from the Middle Sands of Lancashire, in which none but recent shells have been found. These include *Buccinum tenerum*, *Fusus antiquus*, *F. scalariformis*, *Nassa incrassata*, *Turritella incrassata*, *Cerithium punctatum* (*tricinctum*), *Pectunculus glycimeris*, *Nucula Cobboldiæ*, *Astarte borealis*, *Tellina obliqua*, *Mya arenaria*, &c.

It appears, in Mr. Wood's opinion, to have been a littoral marine deposit, and to be unconformable to the Lower Gla-

cial. This is locally the case on the Norfolk coast, where large basins or pockets filled with Middle Glacial sand and gravel have been excavated in the Contorted Drift. Some of these basins or pockets, however, are evidently due to contortion.

Mr. Wood considers that the Middle Glacial deposits are older than any of the shell-bearing glacial beds in other parts of Britain.

UPPER GLACIAL BEDS.

The Great Chalky or Upper Boulder Clay is a clayey deposit full of pellets or pebbles of Chalk, containing also Chalk-flints, blocks of various rocks, many of them scratched or grooved by ice-action.

In thickness it varies from a few feet to 150 feet. It contains numerous fossils derived from various formations, including *Gryphæa incurva*, *G. dilatata*, *Belemnites*, &c.

It is much used for marling fields, whence the number of marl pits. The surface is often very loamy, and in this respect hard to distinguish from the London Clay in Essex:[1] some of these surface beds have been used for brick-making. This surface is frequently 'piped' in the same way as the Chalk, a feature evidently due to a similar cause, namely, the dissolution of the chalky matter by carbonated water. In the pit at Mackie's Nursery near Norwich, the Middle Glacial sands have by this agent been cemented into a comparatively hard rock which has, indeed, been used for building-purposes.[2]

This Upper Glacial clay was, in the opinion of Mr. S. V. Wood, jun., for the most part formed underneath a great

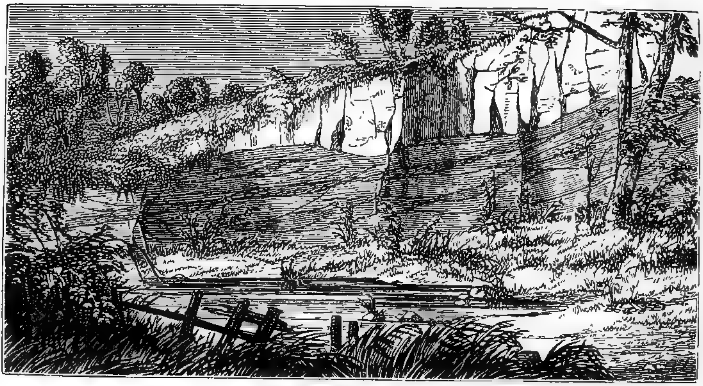
1 Sometimes called the 'Brown Clay' in the Eastern Counties.

2 Partly used in the construction of Norwich Castle. (S. Woodward.)

sheet of ice, and gradually extruded therefrom upon the floor of the sea, which was burdened with floe-ice.

It is well developed in Norfolk, Suffolk and Essex, in the country around Tivetshall, Eye, Framlingham, Halstead, Dunmow, Braintree, and the Rodings, but it has not been met

FIG. 22.—*Section at Writtle, near Chelmsford.*



2. Chalky Boulder Clay. (Upper Glacial.)
1. Sand and Gravel. (Middle Glacial.)

with south of the Thames, nor in the Thames Valley. It occurs at Finchley, at Bricket Wood near Watford, and other places north of London, and around Buntingford, Biggleswade, Huntingdon, Horncastle, &c.

Overlying this Boulder Clay, there are in Yorkshire beds of a purplish-brown colour termed the 'purple clay' by Messrs. Wood and Rome. This clay has the most extensive development of any bed superior to the Chalk in this county, not only overlapping the basement clay in all directions, but extending far beyond the north scarp of the Wolds in an irregular belt along the coast northwards. In its lower por-

tion it abounds with boulders of lower Secondary, Palæozoic, and Metamorphic rocks, and at Holderness it contains small quantities of Chalk. Messrs. Wood and Rome state that in the upper portion the small fragments disappear, and the large blocks also become far less frequent, so that the uppermost part (which at Dimlington can be well contrasted with the lower) is scarcely entitled to the distinction of Boulder Clay.

Bridlington Crag.—In the lower and central portion of the purple clay are some beds of sand and gravel, one of which at Bridlington Harbour (according to Messrs. Wood and Rome) yielded the mollusca first made known by Mr. Bean as from the Bridlington Crag. This Crag is rarely seen now save at low tide. Its thickness is estimated at not more than 10 feet, and its fossils include *Saxicava rugosa, Trophon scalariformis, Astarte borealis, Nucula Cobboldiæ,* &c. More than one-third of the species are arctic in character.

Drifts of South Wales and the South-west of England.

In South Wales there are deposits of drift gravel and boulders, apparently of local derivation, which may yet be connected with the Glacial period. Such are the scattered deposits near Cardiff, Cowbridge, Bridgend, Llantrissant, &c.

There is very little drift on the Cotteswold Hills, but in the neighbouring Liassic vales there is much gravel; this has been divided by Mr. W. C. Lucy and Mr. E. Witchell, into the Angular Gravel of the slopes, the rolled Oolitic Gravel of the river valleys, and the Northern Drift.

Near Bath, on Hampton Down and other hills, fragments of flint and pebbles of quartz are met with.

The Mendip Hills are remarkably free from drift, but there are some deposits of loam and clay, with here and there

a boulder of some local rock, whether Old Red Sandstone or Millstone Grit, whose position cannot well be accounted for by the action of rain, rivers, or sea.

Quartz, granite, and porphyry are found on the high grounds east of Poole in Dorsetshire, and also in the Isle of Wight. (See fig. 20, p. 274.)

In Devonshire and Dorsetshire, on the summits of the hills and high lands formed of the Chalk and Greensand there is generally found a deposit of very variable nature composed of re-assorted materials chiefly from the Chalk and Greensand themselves. The Chalk itself, as is well known, is generally capped by a deposit called Clay-with-flints, this being in great measure due to the dissolution by carbonated water of the Chalk leaving any insoluble portions and the flints behind. These are generally mixed with a considerable proportion of clay, due either to the former presence of Eocene deposits or of Drift clays.[1] This Clay-with-flints is found in many places, but it is associated frequently with deposits of Chert detritus, the chert fragments being sometimes rolled, and often transported to a distance (though not necessarily a great one) from the spots where they originally were formed. The flints from the Chalk are often rolled and transported to positions where they could not have been worked out *in situ*. Mingled with these deposits there is an abundance of small quartz pebbles, and not a few as large as a hen's egg: there are also pebbles of hard quartzose grit and of quartzite which are evidently foreign to the immediate neighbourhood.

Looking at these deposits in a large way, it seems that they may be partly due to the Denudation of the Chalk and Greensand, which was perhaps originally caused by the sea before the escarpments were formed; and they may also have

[1] For farther account of Clay-with-flints, see chap. XI.

been worked up and some of the foreign pebbles introduced during submergence at the Glacial period.

The Gravels and Sands bordering the Bovey Basin near Newton Abbot seem to be connected with the Drifts which cap the Haldon and Blackdown Hills. They appear to have been deposited in this Basin, and perhaps to have filled it, when many of the neighbouring valleys had not been excavated.[1] (See fig. 12, p. 20.)

Mr. Pengelly has described some scratched stones found at Englebourne, and some boulders met with at Waddeton in South Devon, which are suggestive of Glacial action.

In describing the disturbances or 'terminal curvature' of the laminæ of slate in South Devon, Mr. Godwin-Austen observed (more than 30 years ago) that by the action of frost on the exposed edges of inclined slate rocks the laminæ separate, earthy matter is carried in between them, and thus the space they required is gradually increased. He added, that though it would be hazardous to say that these appearances may not have resulted from long-continued action of the actual frosts, yet when we consider the great extent to which this separation of the leaves of the slate has been carried, and the very inconsiderable depth to which frost at present penetrates in this part of England, we seem to require a period with a lower temperature and the action of deeper searching cold.

There are a number of drifts (brickearth and gravel) which have been referred by Mr. Wood to the denudation of the Glacial beds during their emergence from the great depression.

Amongst these are extensive deposits of coarse gravel in the central and eastern part of Norfolk, such as those on

[1] These sands have usually been termed Greensand. The occurrence of the arctic and alpine *Betula nana* in a superficial deposit at Bovey Heathfield, has been noted by Mr. Pengelly. (See p. 331.)

Mousehold Heath and Poringland near Norwich, Wymondham, &c.

Traces of gravel occur further south in Essex on Langdon Hill, in Middlesex on Hampstead Heath, in Kent on Shooter's Hill, &c. They are usually made up largely of flint and quartz pebbles, and are seldom of great thickness, varying usually from 2 or 3 to 10 or 12 feet.

The Tertiary hills of Berkshire and Surrey are capped by gravels of uncertain age.[1]

Hessle and Kelsea Beds.—The district of Holderness in Yorkshire, a tract of low-lying ground south-east of the Chalk Wolds, is made up of an interesting series of gravels, sands, and clays, which have been described by Prof. Phillips, Mr. Prestwich, Mr. S. V. Wood, jun., and others.

The deposits include:—

Hessle (Boulder) Clay, a brick-red clay with a few large pebbles, and characterized by fragments of coal-smut, about 10 feet in thickness.

Hessle Gravel, including yellow sands and gravels, 10 feet in thickness.

They rest upon the Boulder Clay (Upper Glacial).

Mr. Wood considers the Hessle Clay as one of the latest Glacial deposits, formed when the land was emerging gradually from the sea.

At Kelsea Hill near Hull, the Hessle Clay with underlying gravel and sand (Kelsea Hill Gravel) is estimated by Mr. H. F. Hall to have a thickness of 65 feet. The Kelsea Hill bed contains *Cyrena fluminalis*, and marine mollusca, such as *Ostrea edulis*, *Tellina Balthica*, *Buccinum undatum*, *Purpura lapillus*, &c. A similar bed occurs at Paull Cliff.

At Hornsea lacustrine clays occur above the Hessle Clay. (See p. 332.)

[1] In these gravels are found subangular pieces of quartz or rock-crystal called 'Bagshot Diamonds,' which have been drifted far, by many stages, whether from the Breton, Cornish, or Welsh area of old rocks. (T. R. Jones.)

Messrs. Wood and Harmer correlate the gravels of Hunstanton and March, and also the fluviatile deposit of Barnwell in Cambridgeshire, with the Kelsea beds.

They have, however, not been able to trace the overlying Hessle Clay further south than Steeping in Lincolnshire.

Brickearth of the Nar.—With the Kelsea beds may be associated the Brickearth of the Nar, so well known through the labours of Mr. C. B. Rose.

The Nar is a tributary of the Ouse, and the brickearth, a bluish sandy clay, has been traced from Narford to Watlington. It has a thickness of 20 feet or more, and contains, amongst other shells, *Turritella communis*, *Aporrhais pes-pelicani*, *Ostrea edulis*, *Litorina litorea*, *Natica nitida*, &c. The shells are in fine preservation; and there can be little doubt, according to Messrs. Wood and Harmer, that the deposit was formed in an estuary connected with that sea, which a Post-Glacial depression, shown by the Hessle beds, caused to overflow the lower elevations of the eastern side of England.

Sands and gravels containing marine shells, many of them now existing in British seas, but which indicate on the whole colder conditions, have been found at the heights of 1,200 feet at Macclesfield, and 1,350 feet at Moel Tryfaen near Caernarvon.

At Macclesfield, according to Mr. R. D. Darbishire, the shells include *Cytherea chione*, *Cardium rusticum*, *Arca lactea*, *Tellina Balthica*, *Cyprina Islandica*, *Astarte arctica*, *Turritella communis*, &c.

At Moel Tryfaen the following mollusca are most abundant, *Tellina Balthica*, *Cyprina Islandica*, *Cardium edule*, *Turritella communis*, *Fusus antiquus*, &c. The Drift here is described by Mr. Mackintosh as consisting of 35 feet of

irregularly stratified gravel and sand, which rises from the floor of the highest excavation of the Alexandra Slate Quarry to within a few yards of the rock-crested summit of the hill.

In the opinion of Mr. Wood, it has not yet been satisfactorily shown that these deposits are the equivalents of the Middle Sands of the Lancashire coast. These latter, at Blackpool Cliff, &c., have yielded *Nassa reticulata*, *Buccinum undatum*, *Aporrhais pes-pelicani*, *Purpura lapillus*, *Litorina litorea*, *Astarte borealis*, *Cardium edule*, *Tellina Balthica*, *Ostrea edulis*, *Mytilus edulis*, &c. Similar shells occur in the Lower and Upper Boulder Clays of North Wales, Cheshire and Lancashire, and Mr. S. V. Wood, Jun., regards this Upper Boulder Clay as not improbably the same as the Hessle Clay. (See p. 305.)

Turning to the south coast of England, we find at Brighton, and westwards, between the Chalk-hills and the sea, that the surface of the country is formed, first, by a raised terrace of 'red gravels,' lying on the sloping base of the Chalk-hills, and on the old Tertiary deposits; secondly, by the gravels of the Chichester Levels, or the 'white gravels.' These latter are distinctly bedded and seamed with sand, and are more water-worn than the red gravels which pass under them; and thirdly, the white gravels are overlaid by 'brickearth,' which is somewhat variable in its characters. These, with their equivalents, are described by Mr. Godwin-Austen as the Glacial deposits of the district.

At Selsea the Glacial deposits are about 25 feet in thickness, and contain a variety of pebbles and boulders of granitic, slaty, and old fossiliferous rocks.[1] One boulder measured 27 feet in circumference.

[1] Near Selsea, on a branch of Pagham Harbour, there is a remarkable phenomenon called the 'Hushing Pool.' This, according to Mr. P. J. Martin, is simply the bubbling and hissing produced by the disengagement of the air from the gravel before the incoming tide.

Mr. Godwin-Austen thinks it probable that the superficial brickearth of the district under notice was formed in a land-locked lagoon, subject to periodical freezing; and that the 'Elephant-bed' at Brighton is one of its many and variable equivalents (in this case probably subaërial).

Sir Charles Lyell, speaking of these deposits, remarks that they are the most southern memorials of ice-action and of a Post-pliocene fauna in England. A marine deposit, exposed between high and low tide, occurs on both sides of the promontory called Selsea Bill, in which Mr. Godwin-Austen found thirty-eight pieces of shells, and the number has since been raised to seventy. This assemblage is interesting because, on the whole, while all the species are recent, they have a somewhat more southern aspect than those of the present English Channel. What renders this curious is the fact that the sandy loam in which they occur is overlaid by yellow clayey gravel with large erratic blocks which must have been drifted into their present position by ice when the climate had become much colder. These transported fragments of granite, syenite, and greenstone, as well as of Devonian and Silurian rocks, may have come from the coast of Normandy and Brittany, and are many of them of such large size that we must suppose them to have been drifted into their present site by coast-ice. The gravel contains a few littoral shells of living species, indicating an ancient coast-line. (Lyell.)

At Brighton, east of Kemp Town, the beds exposed are:—

	Feet
Soil, &c.	
'Elephant Bed'	50 to 60
Old sea-beach	5 to 8
Sand	3 to 4
Chalk.	

The Elephant Bed, provincially termed Coombe rock, is

chiefly made up of chalk rubble. It contains remains of the Mammoth (*Elephas primigenius*), Horse, Ox, Red Deer, Whale, &c.

MARINE DEPOSITS.

Raised Beaches.

These consist of accumulations of sand and shingle generally containing recent marine shells, which have been formed by the sea, but yet occupy such positions at a height above the present reach of the breakers, as to necessitate the opinion that changes of level in the land have taken place since their deposition.

As Mr. Kinahan has pointed out, littoral deposits may be accumulated at varying levels at the present day, owing to the variations in tide heights in different localities. Therefore if we find raised beaches occupying different elevations in a certain district, it does not necessarily follow that the land has been unequally uplifted since the formation of the beaches.

Our Raised beaches may be connected with oscillations that occurred in the Glacial period. Long ago, in describing the raised marine beds on the Devon coast, and commenting upon the paucity of the molluscan remains contained in them, Mr. Godwin-Austen observed that not only are the characteristic forms of our south-western coasts entirely wanting, but we miss all those other shells which any beach, at the present day, would readily supply. This is only negative evidence, but it suggests that the period of these raised deposits may have been one less favourable than the present to the development of marine life, owing, perhaps, to a lower temperature; such as the broken up or detrital edges of the slate rocks would also indicate. (See p. 317.)

Raised beaches are not uncommon along the coasts of Devon and Cornwall, occurring at Hope's Nose and Thatcher Stone near Torquay, Slapton, Plymouth, St. Blazey Bay (Polkerris), Falmouth Bay, The Nare, Coverack Cove (flints), in and near Mount's Bay, Cape Cornwall, St. Ives Bay, Towan Head, near Trevose Head, near Pentire Point, and Bideford Bay.

Raised beaches also occur at Weston-super-Mare, and at the Mumbles, near Swansea.

On the Dorsetshire Coast the Raised beach at Portland is well known.

Mr. T. Codrington has described the remains of an old sea-bed at Avisford and Waterbeach with marine shells at from 80 to 100 feet above the sea-level.

Recent Marine Deposits.

Deposits of marine sand and shingle containing sea-shells occur in some places inland at about the present sea-level. Such deposits show the former extension of the sea over the area.

Burtle Beds.—In a few places in the Somersetshire moorlands deposits of this nature may be found, and being well exhibited at Burtle they have been termed the Burtle Beds. At several places in the moorland the ground rises into gentle hills, generally banks of Red Marl, with fringing and outlying beaches composed of sand with recent marine shells, the common cockle, oyster, and periwinkle, *Pholas dactylus*, *Nassa reticulata*, &c. These indicate a recent encroachment of the sea. According to Messrs. Buckland and Conybeare these old lines of beach may be traced along many parts of the border of King's Sedgemoor, viz., at Sutton, Chedzoy, Weston Zoyland, and Middle Zoy, of which places the three latter retain, in the etymology of their names, the evidence of their former maritime position.

Calcareous sands are sometimes compacted by rain. Prof. A. H. Church has directed attention to an instance at Bude-Haven, in Cornwall, of the consolidation of sea-sand by means of land-springs. The cementing action was due to the re-precipitation, between the sandy particles, of carbonate of lime—this substance being originally derived from the shelly débris of the sand itself, and being held in temporary solution by carbonated water. (See remarks on Blown Sands.)

At Babbicombe Bay portions of the shingle beach are cemented into a conglomerate by calcareous springs.

Shingle Beaches.

The formation of shingle beaches and their mode of occurrence in different localities is too extensive a subject to be dealt with here, and would not be altogether in place; but it will be well to refer to some of the more extensive beaches which are of geological interest.

The travelling of shingle beaches (to quote De la Beche) is modified by many circumstances, and there is not unfrequently a conflict between the sea and a river. The results necessarily depend upon the general power of each action. Usually the breakers gain, so as to produce a long line of shingle, turning the course of the river, until the latter obtains support from a hard cliff, and is no longer forced aside, or the river perhaps percolates through the shingle.

Such is the case along the southern coast of Devon between Exmouth and Axmouth, also on the Suffolk Coast the Orford Beach (derived chiefly from the Middle Glacial gravels) is worthy of mention.

The shingle about Romney Marsh, including Dunge Beach, is three miles long and one to three miles wide, and formed of pebbles which have come from the west.

Chesil Bank.—A continuous bank of shingle extends from Burton Bradstock to Portland, a distance of about fifteen

miles. It varies in breadth from 170 yards near Abbotsbury to 200 yards at Portland. From Burton Bradstock to Abbotsbury it touches the shore, but eastwards it is separated from the land by the Fleet.

The pebbles increase in size eastwards from sand and fine shingle at the western extremity of the beach.

They consist of Chalk-flints, Greensand chert, Portland rocks, quartzite (from the Budleigh Salterton pebble-bed), quartz, porphyry, granite, jasper, &c.: all have come from the west.

Several theories have been proposed to account for the formation of the Chesil Bank. That the Isle of Portland, acting as a natural groyne or breakwater, was essential to the collection of the material, all admit. The partial separation of the bank from the land is the source of much discussion. Messrs. H. W. Bristow and W. Whitaker consider that the Chesil Bank may have been formed at first in the same way as the ordinary shingle beaches of our coast, and that what was once an ordinary beach, banked up against the land, has been since separated, as a bank or bar, by the denudation of the land behind it. This they consider due to the action of the streams which originally filtered through the shingle, turning eastwards before doing so, as do other streams further west on the Devon coast. In time these streams gradually united and formed a long channel between the beach and the mainland. This water might have been materially widened by tidal action, which would assist it in cutting back the land.

Prof. Prestwich considers that the Shingle is chiefly derived from the materials of the Raised beach of which a remnant still exists on the Bill of Portland.

ALLUVIAL DEPOSITS.

The deposits of existing rivers and estuaries may all be classed under the above heading. They include gravel, sand, brickearth or loam, mud, clay, and silt. Peat, too, may be included, as it is formed in swamps along the borders of rivers, and may occur interstratified with other materials in the section of the fluviatile or estuarine deposits. Three divisions only are generally made in the Alluvial deposits: (1) Alluvium proper, being the latest sediment; (2) Brick-earth, or old Alluvium, occupying a position generally above the area ordinarily flooded by the river; and (3) Gravel and sand, also at a higher level than the Alluvium. These divisions are in a great measure indefinite, as all the different kinds of *material* may have been formed and deposited contemporaneously. Mr. Prestwich has pointed out that in all rivers subject to floods and carrying down much sediment, as for example, the Severn in its lower course, three forms of sediment will be deposited: 1st, coarse gravel and shingle in the more direct channel through which the waters flow with the greatest velocity; 2nd, sand and fine gravel in those portions of the more direct channel where the velocity of the stream is checked from any cause; and 3rd, fine silt and sediment in those parts where the flood-waters out of the direct channel remain for a time in a state of comparative repose; such places are the lee-side of the hills, lateral valleys and plains, with any local depressions or hollows. None or little would accumulate in the main channel, as the scour of the retiring waters would there prevent its deposition.

Alluvium.—Those who wander along the banks of our rivers will observe the flats of marsh or meadow land that usually flank them, bordered now on one side, now on the

other by a cliff, and marked off from the surrounding country which rises gently or abruptly from it.

This tract of level ground forms what is called Alluvium, and it is evidently composed of material deposited by the river.

If we examine its banks we generally find a loamy or silty deposit with seams of gravel: sometimes the entire bank is composed of gravel, at others nothing but loam or very sandy clay may be seen. In the finer sediments we may often find remains of the common river shells and perhaps a few land shells and bones of recent mammalia, as well as works of man.

In clayey countries the Alluvium is generally broad, and not always to be readily distinguished, as the ground rises so imperceptibly away from it. In mountainous regions the Alluvium is more marked, but the material composing it is generally very coarse, and often in such tracts it forms an irregular surface, especially if the stream is liable to become a torrent.

The level of the Alluvium naturally falls with the descent of the river, but it may generally be defined as that tract which would be flooded, should the river overflow its banks.

As each river is continually changing its course in its valley, so is it easy to understand the great breadth of many valleys when compared with the size of their rivers or streams, for it does not follow that any river existed of sufficient bulk to fill the entire valley, but that the river has itself constantly changed its position, and worn away cliffs so as to form and occupy different portions of the valley at different times.

The Alluvium where it runs out towards the sea is often of an estuarine character: the term Warp is sometimes applied to the tidal alluvium.

Brickearth.—This consists of a mixture of clay and sand (loam) in varying proportions. In general it is of a brown colour mottled with red.

Gravel.—The Gravels that are met with in our river-valleys, and which are evidently connected with similar areas of drainage, are yet not always easily explained.

Their varying elevation in connection with the level of the present rivers and streams has led to a rough classification into:—

Low-level or Valley gravel.
High-level valley or Terrace gravel.[1]

It must, however, be borne in mind that as the source of a river is so much higher than its mouth, so are the deposits which it has formed at similar periods much higher in elevation as we proceed upwards along its banks; therefore these divisions are very ambiguous.[2]

At the same time in considering their method of formation a glacial gravel may merge in the lower part of a valley into a river-gravel, which would lead one to conclude that some river-gravels may possibly be as old as the Glacial period.

It may also be observed that the great expanses of river-gravel are generally formed in districts where there is much old marine or Glacial gravel, from which it has been largely derived. Much of the Thames Valley gravel is only derived from pre-existing Glacial gravels, which are themselves made up in great part of old shingles belonging to the Tertiary and Triassic periods.

Contortions in gravel (analogous to those in the Contorted drift) are attributed by Mr. Prestwich to river-ice grounding on the soft deposits. Some of the larger blocks of stone in river-gravel may, it is considered, have been transported by river-ice.

[1] The term High-level gravel was formerly applied to the Drift.

[2] Mr. A. Tylor regards the higher and lower gravels as of the same age, believing that, at the time of their accumulation, the rainfall was excessive: hence he applied the term 'Pluvial Period.'

Alluvial soils are generally fertile, forming rich meadow and pasture land. The principal of these are situated on the banks of the Derwent, Ouse, Trent, Humber, Thames, Avon, Wye, Monnow, Usk, Severn, and the flats bordering the Bristol Channel.

The Alluvial silty deposits are sometimes of economic value; sand from the bed of the Thames being useful in brickmaking.

Portland cement has been made from mixed river-mud from the mouth of the Thames.

At Watcombe, near Torquay, a clayey deposit formed partly of Triassic soil and partly of Devonian slaty soil has been used in the manufacture of red terra-cotta.

The larger tracts of Alluvium coloured on our Geological maps include the following districts:—

(1.) Fleetwood to near Liverpool, two masses separated by the River Ribble.

Mr. T. Mellard Reade, describing the Post-Glacial Deposits of Lancashire and Cheshire, has divided them as follows:—

5. Tidal Alluvium and Blown Sand.
4. Superior Peat and Forest-Bed, 2 or 3 to 20 feet.
3. Formby and Leasowe Marine Beds, resting unconformably upon lower and older beds.
2. Inferior Peat and Forest-Bed.
1. Washed Drift Sand (= Upper Drift Sand of Mr. G. H. Morton, and Shirdley Hill Sand of Mr. De Rance) 12 to 15 feet, resting unconformably upon the Boulder Clay.

Mr. C. E. De Rance, treating of the same district, has made the following local divisions:—

Recent .	Upper Cyclas Clay, with *C. Cornea*, and Scrobicularia Clay with *S. piperata*.
Pre-historic.	Upper Peat, 12 feet. Lower Cyclas and Scrobicularia Clay, 20 to 30 feet.
Post-Glacial.	Shirdley Hill Sand, with *Cardium edule* and *Turritella communis*, 15 feet. Lower Peat, 2 ins. to 10 feet.

(2.) A second tract of Alluvium is present at the northern part of the Isle of Man. (See p. 305.)

(3.) A tract of Alluvium extends along the borders of the Bristol Channel between Chepstow, Newport, and Cardiff, and between Berkeley and Portishead. It spreads out near Clevedon, Weston-super-mare, Burnham, Glastonbury, Bridgewater, Langport, and Ilchester.

The Somersetshire Levels exhibit a very variable series of beds.

The following section at Huntworth near Bridgewater was noted in 1826 by W. Baker:—

	Feet
Silt	16
Peat in two strata of irregular thickness, with Shells, Bones, horns of Deer, and Wood. Upper stratum coarse, and containing fresh-water and marine shells. Lower stratum fine, containing a great number of fresh-water shells only. Compressed Alder branches, showing the silvery bark very distinctly	1
Soft silt	9
Gravel, like that resting on the marl at Bridgewater, and containing shells, pottery, and bones of horse, ox, and deer, all, like the gravel, of a dark colour	1
Blue clay, penetrated by roots and rootlets of plants	2
Red Marl, 29 feet below the surface, which was a little below the level of the highest spring-tides.	

The Bridgewater Levels furnish some of the richest grazing lands in the kingdom. Since the commencement of the present century vast improvements have been made in reclaiming wet bog land in this large tract of flat country. Draining and 'top-dressing' with river-mud have done wonders, so that in place of the bog plants, clover and almost every description of meadow grass will thrive.

Even now, when heavy rains have fallen, the Parret and its tributary streams rise above their banks and flood large tracts of country. The fall of the Yeo is about an inch per mile for a long distance, so that the stream is too sluggish to

carry off the drainage in very wet weather. Langport then lies on the edge of a vast sheet of water, and some of its streets are often flooded. Aller, close by, is an island, while far away sheet after sheet of water spreads out, and these give the country a totally different appearance, much enhancing its beauty, although not in the eyes of the farmers, whose loss is very great, and when once the waters break loose, many months may elapse before they disappear.

At Bridgewater brickyards are made the celebrated Bath bricks, named (so my friend Mr. Ussher tells me) from a gentleman named Bath, who at one time was the manufacturer. These bricks, which are merely shaped in the form of an ordinary brick for the sake of convenience, and are used for scouring, polishing, knife cleaning, &c., are made from a peculiar kind of sand obtained from the bed of the River Parret, or from reservoirs into which the river overflows and leaves a deposit. It consists of siliceous sand, containing remains of diatomaceæ.

Here and there in the valley, at Larkhall near Bath, Bathampton and Freshford, small patches of gravel have yielded the remains of Elephant, Rhinoceros, Wild Boar, Musk Ox or Arctic Buffalo, &c.

In the valley of the Severn there is much drift. At Cropthorne on the Avon, between Evesham and Pershore, Mr. Strickland obtained bones of *Hippopotamus*, *Bos Urus*, *Ursus*, &c.; also many land and fresh-water mollusca.

Sir R. I. Murchison and Prof. Buckman have recorded marine shells of existing species from some of the gravel beds in Shropshire, Staffordshire, and Worcestershire: whence they were led to infer an 'Ancient Strait of Malvern.'

In the Bovey Basin between Bovey Tracey and Newton Abbot there are accumulations of sand and gravel which rest on the Miocene deposits, and are called the 'Head.' These

are for the most part recent fluviatile and estuarine deposits, and are partly made up of older gravels which border the basin. Near Kingsteignton a bronze spear-head, a wooden doll or idol, and several bones of ox, deer, &c., were obtained from one of the pits. (See p. 317.)

At Fisherton near Salisbury the valley drifts have yielded remains of the Greenland lemming, Mammoth, Rein-deer, Cave hyæna, and Flint Implements.

In the Isle of Wight, at Tollands Bay, there is a lacustrine deposit (described by Mr. Bristow) containing recent species of *Helix*, *Cyclostoma*, *Succinea*, *Limnœa*, *Planorbis*, &c.

(4.) At Romney Marsh the whole of the Alluvium, according to Mr. F. Drew, is below the level of high water at spring tides, but the access of the sea is prevented by tracts of shingle bordering the marsh, which are partly piled above the level of high water, and by artificial walls which have been erected where no natural barrier of shingle exists.

A superior kind of brickearth has according to Mr. Bensted been worked near Maidstone. It occurs in faults in the Kentish Rag, and is an old fluviatile deposit.

(5.) A fifth large district includes the district known as Holderness in Yorkshire (see p. 318), the eastern borders of Lincolnshire, and the Fenland.

At Holderness the following is the general section :—

	Feet.
Soil	1
Clay	6
Silt	23
Peat with large trees	2

Lacustrine deposits with *Cyclas* (Cyclas-marls), *Paludina*, &c., have been detected at Holympton, between Withernsea and Owthorne, and near Hornsea.

At Hornsea the beds, seen at low tide, were thus noted by Prof. Phillips :—

Blue clay	2 or 3 feet.
Brown clay, *Anodon*	1 to 3 ,,
Laminated plant-bed	3 in.
Cyclas-marls	4 in. to 1 foot.
Peat and black root-bed	6 in.

According to Prof. Ramsay, the Wash, now a vast plain, was once a great estuarine bay, formed by the denudation of the Kimeridge and Oxford Clays. It has been and still is the recipient of the mud of several rivers, the Ouse, the Nen, the Welland, the Witham, and the Glen.

Here and there are beds of gravel, peat-beds with mammalian remains, and marine clay. (See p. 319.)

A small tract of Alluvium extends from near Hunstanton to near Weybourn on the coast of Norfolk.

At Yarmouth the alluvial or estuarine silt has been proved to a depth of 170 feet.

In the Cliff section at Mundesley, on the Norfolk coast, is a freshwater deposit, resting in a trough of the Glacial deposits, and consisting, according to Mr. Prestwich, of sand and black and brown peaty beds, containing some bones, recent freshwater shells, insect and fish remains. The lowest beds consist of subangular flint-gravel. Deposits of somewhat similar character occur at Bacton, and also at Hoxne, where the gravel contains flint implements.

(6.) At the Mouth of the Thames, at Sheppey, Shoeburyness, Foulness, and at the mouths of the Crouch, Blackwater, and Colne, there are considerable tracts of Alluvium. A neck of it separates Thanet from the mainland.

At Copford in Essex beds of blue brickearth have been extensively worked, and from them a number of recent land and freshwater mollusca were obtained by Mr. John Brown of Stanway. In this deposit (as well as in many other clayey deposits) are many concretions of carbonate of lime, called 'race,' which Mr. H. C. Sorby examined, and con-

sidered to be formed from a mixture of chalk and fine clay, since consolidated by the action of carbonated water; this process having in some cases spread from definite centres, has given rise to the nodular portions.

Remains of Bear, Beaver (two species), Elephant, Hippopotamus, and Stag have also been recorded from the Copford deposit. Similar deposits occur at Marks Tey and Witham.

At Stutton, on the estuary of the Stour, *Cyrena fluminalis* has been found.

At Clacton-on-Sea is a great thickness of gravel, described by Mr. W. H. Dalton as containing a deposit of laminated clay, full of vegetable remains, with freshwater and land shells. It is said that bones of several species of land mammals were found at the base of it. Over this is a fluvio-marine sandy loam, with *Cardium edule*, *Paludina*, *Limnæa*, &c. The age of this deposit is regarded by Mr. Dalton as very uncertain, the gravel being isolated from all deposits of undoubted horizon, and the fossils being such as range from the Pre-Glacial epoch into late Post-Glacial times.

At Lexden remains of Elephant and Rhinoceros have been found in the Brickearth.

The deposits of the Thames Valley have formed the subject of much discussion. They include, according to the classification of Mr. S. V. Wood, jun.:—

Peat and Marsh Clay (Alluvium).

Upper Brickearth, 5 to 8 feet, seen at Wanstead, Tottenham, West Drayton, &c.

Thames Gravel, 12 to 15 feet in thickness.

Lower Brickearth, 20 to 30 feet, seen at Uphall, Ilford, Crayford, Erith, Wickham, &c. It contains *Cyrena fluminalis*, and many Mammalian remains.

Mr. Wood considers that the Lower Brickearth is overlaid unconformably by the Thames gravel, and that it is distinguishable from the Upper Brickearth by its resting directly upon either the London Clay or the lower Eocene

strata. The Grays Brickearth he considers more recent than the Upper Brickearth: it contains *Cyrena fluminalis* and other freshwater shells; also *Elephas* and *Hippopotamus*.

The Thames gravel Mr. Wood considers to be a marine deposit in its eastern portion.

The lower part of the present valley of the Thames he regards as of more recent date than the deposits which it contains that are older than the Marsh Clay, the old valley having been formed by denudation during emergence from the Upper Glacial sea.

None of the Upper Glacial deposits descend into the old valley, although they cap some of the bordering heights to the north.

Amongst the Mollusca recorded by Mr. Boyd Dawkins from the Lower Brick-earth are *Cyrena fluminalis*, *Cyclas cornea*, *Unio litoralis*, *Planorbis corneus*, *Paludina vivipara*, *Ancylus fluviatilis*, &c. The Mammalian remains include *Felis spelæa*, *Hyæna spelæa*, *Ursus spelæus*, *U. arctos*, *Canis lupus*, *Bos primigenius*, *Bison priscus*, *Megaceros Hibernicus*, *Cervus* (two sp.), *Elephas* (three sp.), *Rhinoceros* (three sp.), *Hippopotamus*, *Castor*, &c.[1]

In the valley of the Medway are extensive deposits of gravel, containing Mammalian remains in places.

At Folkestone Battery a bed of gravel called the Bone-bed rests on the Lower Greensand, and is overlaid by a white loam used as brickearth. It has yielded remains of *Bison*, *Bos*, *Cervus tarandus*, *C. elaphus*, *Elephas primigenius*, *Hippopotamus*, *Hyæna*, *and Rhinoceros*.

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[1] For the collection and preservation of a number of specimens found at Ilford we are largely indebted to Sir Antonio Brady, and to Mr. William Davies.

In the Gravels and Upper Brickearth of the Thames Valley flint-implements, evidently fashioned by man, have been found, and associated with them in the same deposits occur remains of the Bear, Wolf, Fox, Hyæna, Cave-lion, Bison, Irish Elk, Musk Ox, Elephant (Mammoth), Rhinoceros, Hippopotamus, &c.

The past is so linked with the present that no definite line of demarcation can be drawn between the province of Geology and that of Archæology.

Mr. Prestwich has observed that 'In almost every instance the flint-implements have been found in beds of sand and gravel along the line of existing river-valleys—in some cases but little above the river.'

In treating briefly of these discoveries other districts besides the Thames Valley may be referred to, and it may be well to give the general classification used by Archæologists.

In speaking of the Stone Age, the Bronze Age, and the Iron Age, Archæologists indicate phases in civilization. Thus the implements and weapons of Stone have been shown to have preceded those of Bronze, which again are types of an earlier stage than those of Iron.

The Stone age is characterized by works of very different type, indicating two periods called the Neolithic or New Stone, and the Palæolithic or Old Stone period.

The implements of the newer type are generally well shaped and polished, those of the Palæolithic type are rude, being merely chipped. There is no transition or connecting link between the Palæolithic and Neolithic types, but the latter is easily connected with the Bronze and Iron periods; the gap between the two is indicated by great physical changes, and by differences in the associated animals.

These terms are often misunderstood. Thus the term Neolithic is used to represent a phase of culture which dif-

ferent races reach and pass, and to which a different relative position in time must be assigned in different parts of the world.

Gravels yielding Palæolithic implements so far as observation has gone, are confined to the south, south-east, and east of England.

According to Mr. Evans they occur in the valleys-deposits of the Great Ouse, the Waveney (Hoxne), the Thames,[1] the South Avon, and their numerous tributaries, and at various places along the southern coast of England. North of the Ouse and west of the valley of the Axe, no river-gravels have yielded any Palæolithic implements.[2]

Mr. James Geikie considers that the Palæolithic deposits are of Pre-Glacial and Glacial age, and do not in any part belong to Post-Glacial times. In the Eastern counties all we can say is that the valley-gravels are newer than the Great Chalky Boulder Clay.

[1] Palæolithic implements have been found in the gravel capping the cliffs at Herne Bay.

[2] See *The Ancient Stone Implements, Weapons, and Ornaments of Great Britain.* 1872.

CHAPTER XI.

SUB-AËRIAL PHENOMENA.

THIS term is perhaps open to some objections, but it serves very conveniently to include such deposits as are formed on land chiefly by rain, frost, springs, such as cavern deposits, landslips, and soils; terrestrial beds such as peat; and aërial deposits, as blown sand, &c.

No attempt is made to classify these deposits according to age; some of the cavern deposits may be Pre-Glacial, but as most caverns contain deposits of distinct periods, and as it would obviously be inconvenient to treat of them separately, as also of the method of formation of caverns, all the phenomena are briefly noticed together.

As springs play so important a part in the history of these formations, it seems well to commence with some notice of them.

Springs.

The occurrence of freshwater at different levels beneath the surface of the earth is dependent upon the geological structure.

Thus the rain falling on the surface filters through the porous rocks or finds its way through joints and crevices in denser rocks which generally exhibit its action in furrows and channels, and so it sinks below until it meets with a stratum of clay or marl, two or three inches of which, if continuous, is often sufficient to retain the water, which

either collects or issues at the side of a hill in the form of springs.[1]

On clayey strata the water either collects at the surface or forms natural channels, which carry it away to form streams, which passing over porous strata sometimes *clay* their own beds.

The supply of water in wells depends in a great measure upon the rainfall, but the deeper wells are the more constant because their sources of supply are more widespread. Thus the outcrop of a porous rock may receive a considerable quantity of water, which may be retained within it by the presence of clayey beds both above and below; and should the outcrop be very extensive, and the strata be characterized by a basin-shaped structure, the water will rise (sometimes above ground) to near the level of the outcrop of the water-bearing stratum when tapped at or near the centre of the basin. Upon this kind of structure the system of Artesian[2] wells depends, and it is well exemplified in the London Basin, where the deep wells are situated in the Chalk which crops out to the north-east and south of London, contains at its base the impervious Chalk Marl, and is overlaid by the retentive Lower Tertiary Clays.

Intermittent springs are sometimes fed by reservoirs in the strata which are filled during rainy seasons, and gradually drained off by the springs.

The 'Nailbournes' or intermittent springs of the Chalk tract, according to Mr. C. W. Johnson, are channels used during excessive rain-fall, when the ordinary streams are unable to carry away all the water.

In studying the water-bearing strata, it is interesting to

[1] In sinking a well it is important not to go too near to the escarpment, where the water may be drained off by springs; or too near a fault, where it may be dammed up or drained off.

[2] So named from Artois (Artesium).

trace their connection with the distribution of villages. There is no doubt but that the earliest settlements were fixed according to the means of obtaining a supply of water and one easily accessible.

Mr. Prestwich has shown how the earliest settlements in and around London were dependent upon the geological structure, and for this reason. The London clay, which occupies so large an area, is covered to a large extent by the valley gravels, and in the north of London by here and there an outlying hill of Bagshot sand. Wells sunk through these sandy and gravelly deposits were always supplied with water, which was kept up by the impervious London clay. Hence as the water supply was an all-important question with the early settlers, so they followed the course of the water-bearing strata, while the bare London clay was unoccupied until the New River and other water-works did away with the necessity for wells. Thus the clay districts of Holloway, Camden Town, Regent's Park, St. John's Wood, Westbourne Park, and Notting Hill received town populations much later than Stepney, Hackney, Islington, Kensington, Chelsea, and Camberwell, which are situated on gravel.

In the same way, Mr. Prestwich has pointed out how on the outskirts of London a succession of villages grew up for miles on the great beds of gravel, ranging on the east to Barking, Ilford, and Romford; on the north, following the valley of the Lea, to Edmonton and Hoddesdon; and on the west, up the Thames valley, to Hammersmith, Ealing, Hounslow, and beyond. Around Harrow, which stands on the Bagshot sand, a large area of bare London clay extends, which is remarkably free even now from the encroachment of houses, particularly between Harrow and Ickenham on the west, and Edgware on the north-east.

Similarly limestones, sands, and sandstones, such as the Coral Rag, Cornbrash, Upper Greensand, &c., are often

marked in their outcrop by villages, while the Oxford Clay, Kimeridge Clay, and Gault form in comparison districts very thinly populated.

Well water at moderate depths, 100 to 200 feet, is usually colder in summer and warmer in winter than surface water. In very deep wells the temperature of the water rises at about the same rate as that of the atmosphere in mines—1° for every 60 feet below the first. Thermal springs probably arise from great depths.

Mr. Smyth has remarked that the quantity of water in Coal-mines derived by percolation from the surface decreases in proportion to the depth, and that at depths greater than 500 or 600 yards the mines are dry.[1]

Water penetrating the rocks often becomes charged with many substances which are contained in them, such as sulphur, iron, and salts of lime, soda, and magnesia: hence its medicinal value. When the rocks contain much chloride of sodium, they often give rise to valuable brine springs. (See p. 131.)

The water of clay districts is 'soft' like rain-water, but in limestone areas it becomes impregnated with carbonate of lime, and is called 'hard.'[2]

The softest water is derived from the sandy and clayey districts: thus soft-water is usually obtained from the Bagshot Beds, London Clay, Lower Greensand, Wealden Beds, Upper Carboniferous strata, from the Silurian and Cambrian gritty and slaty beds, as well as from the Igneous and Metamorphic Rocks. Whereas the water obtained

[1] In the Astley Pit of the Dukinfield Colliery, Cheshire, the average rate of increase of temperature is 1° for every 83 feet.

[2] Hardness of water is caused by the Carbonates and Sulphates of magnesia and lime, but chiefly in London water by the Carbonate of lime dissolved by the carbonic acid in the water. From this hardness a difficulty in washing the body is found, from the deposition in the pores of the skin of the insoluble stearate of lime.—Frankland.

from the Chalk, Oolites, Lias, and Carboniferous Limestone is hard. That from the Magnesian Limestone is very hard, and that from the New Red Sandstones is frequently gypseous.

Mineral Springs have been classed as follows:—

Chalybeate, containing iron; with two divisions, *carbonated* and *sulphated*.
Sulphuretted, containing sulphur.
Saline, containing an admixture of salts of soda, magnesia, &c.

Warm springs occur at Buxton, Bakewell, Stoney Middleton, Matlock, Taafe's Well near Cardiff, and Clifton.

At Clifton the Hotwell, which rises from the Carboniferous Limestone, contains as chief ingredients sulphate of soda, carbonate and sulphate of lime, and chloride of sodium. In temperature it varies from 70° to 76°.

The spring at Buxton, called St. Anne's Well, rises in the Carboniferous Limestone, has a high temperature, and contains salts of soda and magnesia.

The most important thermal springs are those of Bath, which are the hottest in England. They have been long renowned for their sanatory properties. The temperature varies at the different springs from 109° to 120° Fahr., but on the whole it is remarkably uniform at all seasons of the year. The discharge of the waters, and the amount of the mineral ingredients held in solution by them, have also, so far as observation has gone, remained constant.

The salts amount to about 144 grains per gallon, and consist chiefly of Sulphates of Lime and Soda, Chlorides of Sodium and Magnesium. Carbonate of Lime, Silica and Oxide of Iron, are likewise present. Dr. Daubeny has ascertained that the daily evolution of nitrogen gas amounts to 250 cubic feet in volume. Carbonic-acid gas is also given off. Professor Roscoe has determined the presence of copper, strontium, and lithium in the waters, whilst Dr. Frankland

has ascertained that they contain a large proportion of organic elements.

The waters unquestionably rise from a great depth; they have been tapped at about the junction of the Keuper and Rhætic beds, and there is no doubt that they spring through the subjacent Carboniferous rocks, as was originally suggested by William Smith, who in 1810, when the Bath hot-springs had failed, or had rather escaped into new channels, undertook, and successfully, to restore the waters to the Baths and Pump-room.

Sir Charles Lyell observes that the shock which opened a communication through the upper rocks (of Secondary age) may have been of much later date than the original fissure.

Referring to the large quantity of nitrogen gas constantly being disengaged, Dr. Daubeny has remarked that the same gas is freely evolved from most thermal springs, the majority of which are associated with volcanos, and that it is likewise evolved from volcanos, both in an active and a dormant condition. He suggested the probability of volcanic action being due to chemical reactions being produced in the interior of the globe between the constituents of air and water on the one hand, and the metallic bases of the earths and alkalies on the other. The Bath springs were therefore probably in some manner connected with the cause of volcanic action.[1]

[1] The study of the Bath springs opens up a number of interesting questions. The origin of the mineral ingredients of these and other springs is no doubt due in a great measure to the presence of some at least of them in the rocks through which the waters pass. At the same time, as Sir Charles Lyell observes, mineral springs may derive an inexhaustible supply, through rents and porous rocks, from the leaky bed of the ocean, and this theory is by no means an unreasonable one, if we believe that the contiguity of nearly all the active volcanoes to the sea is connected with the access of salt water to the subterranean foci of volcanic heat.

The following is a list of some of the principal Mineral springs not before mentioned[1]:—

Ashby-de-la-Zouch (supplied from pit in Moira Coal-field).—Chlorides of sodium and calcium, Bromides of potassium and magnesium, Chloride of magnesium.
Cheltenham.—Sulphate of soda.
Epsom.—Sulphate of magnesia.
Harrogate.—Chloride of sodium, Sulphate of lime, Sulphate of soda (Yoredale Rocks).
Holywell, Flintshire.—St. Winifred's spring (Carboniferous).
Leamington.—Sulphate of soda.
Scarborough.—Carbonate of lime, sulphur, chloride of sodium, iron.
Trafalgar Square.—Carbonate and Sulphate of lime.
Tunbridge Wells.—Carbonate of iron.

Other Mineral springs occur at Builth and Llanwyrtyd in Brecknockshire, and at Llandrindod in Radnorshire.

Swallow Holes.

Sometimes on reaching a limestone formation, as the Carboniferous Limestone, after passing over the outcrop of the Lower Limestone Shales, a stream will follow the clayey strata, and disappear beneath the Limestone in 'Swallet' or 'Swallow' Holes.

Examples of these swallet holes occur at Downhead Mill, near the south-eastern extremity of the Mendip chain; at the village of Priddy; and at Charterhouse, on the south-east flank of Blackdown. The exit of the streams swallowed up may be traced with much probability to the following points: that of the Downhead stream to the limestone chasm about a mile east of the village of Downhead; that of the Priddy rivulet to Wookey Hole, and that of the Charterhouse brook to the foot of Cheddar cliffs.

[1] The term 'Spa' is often given to mineral springs, and takes its name from the town of Spa in Liege, at one time a place of great resort.

The streams which emerge are all greater, indeed, than those engulfed; but this arises probably from the tributary waters which they have received during their subterraneous course. The streams, if excessively flooded, might, after suffering partial engulfment, continue to flow above ground through the valleys of denudation in which the Swallow-holes are situated. (Buckland and Conybeare.)

The same is probably the case with St. Andrew's Well, at Wells in Somersetshire.

Swallow-holes are not uncommon in the Mountain Limestone district of Yorkshire. An account of these has been published by Mr. L. C. Miall. In Craven, Thund Pot and Hellen Pot are amongst the largest. They are sometimes called 'Butter-tubs.' The Swallow-holes are of two distinct kinds, those due directly to erosion and those to subsidence of an undermined crust.

'Subterranean rivers are frequent all over the limestone district. Such are the Manifold, which passes beneath the limestone hills about three miles south-west of Ecton mine in Staffordshire, and after traversing a cavern through the base of the limestone hills four miles in length, re-appears near Ilam. The Hamps river also breaks out near the same place. The Ribble and Greta are underground rivers. Such also are Horton Beck and Bransil Beck, at the foot of Pennygant in Yorkshire. The stream which forms the cataract in Speedwell mine near Castleton is, according to the inhabitants of that place, proved to be the same as the stream which traverses the Peak cavern at that place.'

'The River Aire, in Craven, Yorkshire, issues from Malham Tarn, a circular lake about a mile in diameter, on the summit of a lofty moor. Proceeding hence, it soon loses itself, and descends through a subterraneous passage, whence it again issues at the foot of Malham Cove, a perpendicular limestone rock 288 feet high. During heavy rains the sub-

terraneous passage is not sufficient to carry off all the water, the remainder of which makes its way over the surface, till it reaches the top of the rock, and precipitates itself thence in a magnificent cascade.'[1]

In the Chalk country Swallow-holes are not uncommon, as near Canterbury.

The Mole, as is well known, sinks for a while in the Chalk south of Leatherhead.

In Berkshire the Swallow-holes have been described by Mr. Whitaker. He remarks that they are formed by streams which, rising in the higher ground, flow down the escarpment of the Tertiary beds, until they reach the more pervious and jointed Chalk, into which they sink, or until they come within a short distance of that rock, when they work their way into it through the few feet of the softer overlying beds. In the course of time, through the chemical action of the carbonic acid in the water, and the mechanical action of the water itself, funnel-shaped basins are worn out in the Chalk and the beds above, the operation being made more easy by any pre-existing fissures. These hollows are generally thickly overgrown with vegetation. The streams may often be seen running through them, though sometimes they merely flow into a small pool, the level of the water in which remains the same, notwithstanding the constant flow. These Swallow-holes always occur, in this district, at or near the junction of the Reading Beds and the Chalk, and they are therefore of much use in drawing the line between those formations, especially where there are no sections. (W. Whitaker.)

Tufa.

This is a deposit of carbonate of lime often formed by springs which issue from limestone strata. It frequently

[1] Conybeare and Phillips.

contains impressions of leaves and blades of grass, and specimens of the common land-snails, which have become as it were 'petrified.'

The rain absorbing Carbonic acid from the atmosphere and from the soil, with the help also of vegetable acids, as humic and ulmic, dissolves portions of the limestone, which it parts with again when, on coming to the surface, it loses a portion of the Carbonic acid.[1]

The tufa often contains much earthy and sandy matter, and is generally of a loose and friable nature, but sometimes, as near Dursley, in Gloucestershire, and near Matlock, it forms a hard and durable rock fit for building-purposes.[2]

Petrifying springs occur at Chalford, Somerton on the Cherwell, North Ashton, Marston Lane near Oxford, near Carfax, in several places in Somersetshire, &c. The Dropping Well at Knaresborough is well known.

The deposit is made to form more rapidly by the water falling in spray on the objects to be incrusted.

Caverns.

Caverns are formed in most limestone strata. Many no doubt originate along lines of joints or faults, and consist of a succession of chambers at different levels. They owe their origin to the chemical action of water impregnated with Carbonic acid (as mentioned in describing the formation of Tufa), aided also by the mechanical disintegration of the limestone by frost and other meteoric agencies. The material removed is generally carried away by underground

[1] It is considered that colder water underground can hold more Carbonic acid in solution than the warmer water at the surface, and consequently more Carbonate of Lime.

[2] Portions of old Berkeley Castle were built of Tufa from Dursley.

streams, where the water is unable to give out the Carbonic acid gas which allows it to take up the Carbonate of Lime.

These caverns often contain stalactitic and stalagmitic deposits; also mud, pebbles, and breccia. Bones too frequently occur, some of which may have been introduced from above ground, while others may belong to animals or men who formerly inhabited the cavern.[1]

Caverns are most abundant in the Carboniferous and Devonian Limestones.

Stalactites and Stalagmites.—The deposits of Carbonate of lime found in the interior of Caverns are known under these names. Those adhering to the roof or lining the walls are called Stalactites, those covering the floor are called Stalagmites. They generally occur in inland limestone caverns, and are frequently seen hanging from limestone arches, where their formation is rapid.

These stalactites are formed by the deposition, film by film, of some of the limestone which the rain-water has taken up in solution while penetrating it. This incrustation in process of time attains considerable dimensions in the form of stalactites and stalagmites, which sometimes meet, although the increase is scarcely perceptible to the human eye in a lifetime.

Such deposits indicate a pause or conservative stage in the formation of the cavern.

The famous cavern of Cheddar, in the Mendip Hills, is unequalled in England for the beauty of the stalactites which hang in fantastic shapes from its roofs and arches, or the stalagmites which grow in equally irregular forms from its floors and ledges. The cavern is by no means a large one, its size is surpassed by many others in the Mendip Hills, but its ornamentation certainly renders it the most attractive

[1] These bones adhere to the tongue owing to their loss of animal gluten.

one. It is now lighted up with gas, a great improvement over the old dip candles. By a little stretch of imagination one recognizes the wonderful things pointed out by the guide —here a petrified goose, there a loaf of bread, now a font and a monkey, then a nun and the Black Prince, a jelly glass, some drapery, a mummy, a turkey, a tongue, a flitch of bacon (this is generally present in a stalactite cavern), any number of pillars, and a Hindoo Temple!

The cave at Ingleborough near Clapham, in Yorkshire, is likewise famous for its stalactites: it contains no bones.

In Derbyshire the Caverns contain few stalactites, most of those that formerly existed having been broken off and carried away.

It will be impossible to enumerate all the Caverns, but some of the most important which have yielded bones must be noticed.

Wookey Hole, in Somersetshire, is, however, deserving of mention, being only second in size to the Peak Cavern at Castleton, in Derbyshire.

The most celebrated of the Bone Caverns are those of Kirkdale near Kirby Moorside in Yorkshire, Victoria Cave near Settle, Oreston near Plymouth, Kent's Hole and Brixham near Torquay, Wookey near Wells, Banwell and Burrington on the Mendip Hills, Gower in Glamorganshire, Paviland near Swansea, Pont-newydd, and Cefn in Flintshire.

At Cefn the Cavern, in the Carboniferous Limestone, has yielded *Elephas antiquus*, *Rhinoceros tichorhinus*, *Hippopotamus major*, *Bos*, *Cervus*, &c.

The Brixham Cave, formed in the Devonian Limestone, contained the following succession of beds:—

4. Stalagmite.
3. Limestone Breccia.
2. Cave Earth, reddish loam with angular fragments of limestone.
1. Shingle bed with pebbles of different rocks.

Remains of the Mammoth, Tichorhine Rhinoceros, Horse, Ox, Red Deer, Reindeer, Roebuck, Cave Lion or Tiger, Cave Hyæna, Cave Bear, Brown Bear, Grisly Bear, Fox, Hare, and Lemming, &c., also Worked Flints, were obtained from it.[1]

In Kent's Cavern all these species have been met with, and in addition *Machairodus latidens*, Wolf, Dog, Glutton, Badger, Bison, Irish Elk, Beaver, Seal, &c.

For the constant supervision of the workings in this Cavern, undertaken by the British Association, great credit is due to Mr. Pengelly. He has determined five marked beds in this Cavern, as follows:—

5. Black Mould.
4. Granular stalagmite, coeval with the Tichorhine rhinoceros.
3. Cave Earth, with *Hyæna spelæa*, &c., and flint implements.
2. Crystalline stalagmite.
1. Breccia, with remains of Bear only, and flint implements.

Several inscriptions have been noticed in the Cavern by Mr. Pengelly, the oldest of which bears the date of 1604.

The flint implements found in the breccia and cave-earth are very dissimilar, the former being much ruder than the latter, which were very elaborate, and were associated with bone implements and ornaments. These facts, in Mr. Pengelly's opinion, proved the tenancy of the cave by two distinct races of men, and there was abundant evidence of a long lapse of time between them. Both the races of men were coeval with extinct animals, but they nevertheless represented two distinct civilizations. It is possible that the earliest race may have witnessed the separation of England from the Continent, and its formation into an island.

At Kirkdale Cave remains of Hyæna (indicating 300 animals), Fox, Wolf, Cave Lion, Cave Bear, Elephant, Rhinoceros, Reindeer, Irish Elk, Aurochs, Hippopotamus, &c., have been found.

[1] Reports have been published by Mr. Prestwich and Mr. Pengelly.

The Settle Cave (1,400 feet above the level of the sea) has been explored chiefly by Mr. R. H. Tiddeman, from whose reports the following notes are taken.

The upper bed was formed of stones which had fallen from the roof. Then beneath came a black bed, containing charcoal, and highly artistic enamelled ornaments, showing a date of occupation that was post-Roman. Then succeeded a layer six feet in thickness, in which were found remains of a more ancient race, their flint knives, harpoons, &c. Farther within the cave, these two beds came together, so that the two periods of occupation could not be separated.

Beneath these deposits, classed as Neolithic and Roman, the following beds were determined:—

Upper Cave-earth, with Badger, Reindeer, Horse, &c.
Laminated Clay, with a few small well-glaciated boulders.
Lower Cave-earth, with Hyæna, Brown Bear (?), *Elephas antiquus*, *Rhinoceros hemitœchus*, *Hippopotamus*, *Bos primigenius*, and a human fibula.

The clay found in the cave was believed by Mr. Tiddeman to be of Glacial age, as it contained scratched boulders. If this were the case, it would make the Lower Cave-earth Pre-Glacial.

Pin Hole and Robin Hood's Caves in Cresswell Crags, Derbyshire, have lately been explored by the Rev. J. M. Mello, while the Mammalian remains have been described by Prof. Boyd Dawkins. The succession of beds was as follows:—

5. Surface-soil, with Roman and Mediæval pottery.
4. Limestone-breccia, with bones of Reindeer, Horse, Hyæna, *Rhinoceros tichorhinus*, Flint flakes, &c.
3. Cave-earth, with similar bones, also those of Bear, Cave Lion, and quartzite implements.
2. Red sand, &c., with remains of Reindeer, Bison, and *Elephas primigenius*.
1. Sand, with blocks of limestone.

Professor Ramsay has observed that it is impossible to fix with accuracy the precise age of such Caverns, or the time when all the bones that are found in them were buried there; for the wearing out of the caves has been going on for unknown periods of time, and some of them have been filled with sediments, perhaps charged with bones, again and again. There is often proof that, by underground changes of waterflow, old consolidated gravels that filled them to the roof have been, at various periods, forcibly cleared out by natural means. When, therefore, we find bones in these Caverns, mixed with red loam, sand, gravels, and angular fragments of rock, it is often very difficult, or impossible, to define to what precise *minor period* they belong.

Fissures containing bones are not unfrequently met with, as at Bath and Portland, in the Oolitic limestones.

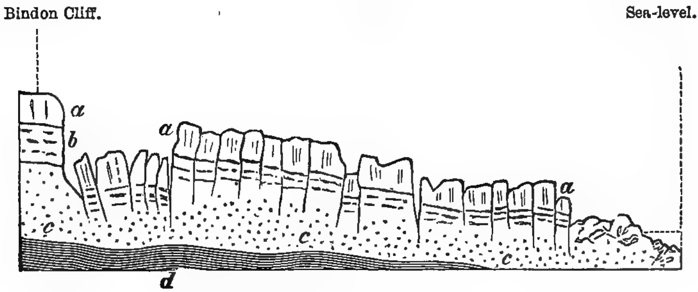
In some of the Mountain Limestone tracts, as on the Mendip Hills, there are numerous veins, filled with Liassic and Rhætic material, which have been described by Mr. Charles Moore. It is, however, impossible to fix with certainty the age in which this débris was introduced.

Landslips.

These are due to the action of rain, rivers, or sea in undermining strata and causing the superincumbent strata to slip over those subjacent. They occur along escarpments and cliffs where the strata dip outwards towards the valley or sea as the case may be. The subjacent stratum must be of a clayey nature, impervious to water, and the tendency therefore of the overlying beds is to slip over it. The action of rain in loosening the bed, and that of frost in producing vertical cracks parallel to the line of cliff or escarpment, greatly tend to promote landslips.

Some of the most striking instances occur along the south coast of Devon and the coast of Dorset between Sidmouth and Lyme Regis. At Dowlands the Chalk and Greensand stretch over the denuded edges of the Lower Lias, Rhætic beds, and Red Marl, all of which are of a clayey nature. The Cretaceous beds dip slightly towards the sea, and numerous springs are given out at the junction of the Greensand with the lower Secondary strata. Portions of the lower sandy beds of the Greensand moreover would be actually removed by springs. Therefore we have every condition favourable to the production of landslips, and they have

FIG. 23.—*Diagram-section of Landslip near Lyme Regis.*



a. Chalk. *b.* Chert Beds, *c.* Sands. } Upper Greensand. *d.* Rhætic Clays.

occurred in great magnitude along the coast at different periods. The great landslip of Bindon took place at Christmas 1839. (See fig. 23.)

The length of the great chasm caused by this subsidence was 1,000 yards, the breadth 300 yards, and the depth varied from 130 feet to 210 feet. Twenty-two acres were sunk in the chasm.[1]

Landslips have occurred along the coast between Flam-

[1] A model of this landslip by Mr. W. Dawson may be seen at the Museum in Jermyn Street, London. Fig. 23 is partly taken from a drawing by Mr. Dawson.

borough Head and Filey Point, where the Chalk and Speeton Clay are exposed.

They are not unfrequent in the London Clay cliffs of Sheppey.

In the Isle of Wight the beautiful scenery of the Undercliff has been produced by the Upper Cretaceous strata, Chalk and Greensand, foundering over the Gault Clay, which for this reason has been called 'the blue slipper.' There is an Undercliff also at Folkestone.

Large landslips occur in the Woolhope district, where the Upper Ludlow rocks, owing to their jointed nature and steepness of dip, have tumbled into the valleys.

In the neighbourhood of Bath vast masses of the Great Oolite are frequently spread over the slope of the Fuller's Earth, and the Inferior Oolite is similarly tumbled in places over the Lias.

Æolian or Blown Sands.

On coasts where a great quantity of sand is formed, and which is exposed to the winds at low tide, hillocks or 'dunes' of sand are raised along the shore, and the ground for some distance inland is coated with a sandy soil. Sometimes the beds of Blown Sand contain marine as well as common land shells,[1] as on the hill above Sennen Cove, overlooking Whitesand Bay (Land's End), and on the Warren at the mouth of the river Ex. Wind 'ripple marks' are sometimes met with.

Blown Sand occurs at Phillack, Upton, and Gwythian Towans, near Phillack and Lelant, at Perran, and Constantine

[1] It is necessary to be particular in discriminating between such deposits and Raised Beaches. See Pengelly on Raised Beaches, *Trans. Devon Assoc.* 1866.

Bay, in Cornwall;[1] also at Braunton Burrows, Burnham, and Woodspring, near Candleston Castle (South Wales), Barmouth, &c.

In the district between Liverpool and Southport, and in that of Wirral, are certain sand dunes, the base of which Mr. De Rance found to consist of a bed of sandy silt, the result of wind blowing sand into pools in which peat was forming. It contains *Bithynia tentaculata*, and he has named it the Bithynia Sand.

Much Blown Sand also occurs at Lowestoft, and along the Norfolk coast, also at Romney, and at Poole in Dorsetshire.

The formation of sandstone generally is instructively illustrated by recently-consolidated sand at Newquay in Cornwall, and many similar examples exist around our western coasts, where hills of Blown Sand prevail. The water percolating through the upper layers dissolves the carbonate of lime, or of iron, and sometimes silica, which are re-deposited as cementing materials, on the evaporation of the water as it filters through the lower strata of the porous sand.[2]

Submarine Forests.

While the Raised Beaches indicate an upward movement in the land, there are many traces of old land surfaces along our coasts, submerged or partly so, which contain fragments and stumps of trees, sometimes erect and with their roots embedded in the old soil on which they grew. They occur in estuaries or near the mouths of rivers.

[1] Towan (towyn) means *Downs;* Les Landes, or 'barren heaths,' is a sandy district on the south-west coast of France, hence Lelant. (Edmonds.)

[2] Hunt and Rudler, Descriptive Guide to the Museum of Practical Geology.

Such Submarine or Submerged Forests may be of very different dates, according to the organic remains they may contain. For instance, the Cromer Forest Bed (see p. 291) is of Pre-Glacial age.

Submerged forests occur at Poole Harbour, off Bournemouth, Southsea Castle, Pagham, Bracklesham, and Portsmouth.[1]

At Portsmouth it is considered that the washing out of an overlying sandy stratum may have produced inundation and the appearance of submergence: a cause which it is considered may have influenced the production of other so-called Submerged Forests.

A Submerged Forest occurs at Porlock Bay, and another at Swansea Bay. That at Stolford and Bridgewater Bay seems to be connected with the peat-beds of the Somersetshire Levels. (See p. 330.) A similar Submerged Forest has been noticed at Sharpness, Gloucestershire.

Numerous Submerged Forests have been noticed on the coasts of Devon and Cornwall.

In South Devon they occur in Torbay, at Blackpool, at North and South Sands in the Salcombe estuary, and in Bigbury Bay, &c.

Mr. Pengelly has stated that we may not unreasonably believe that, if attention were given to the subject, they might be detected beneath the extensive sands which occupy other parts of the coast line. During stormy seasons, these sands are liable to sudden and great displacements. Were opportunities of this kind carefully watched, we should probably find that, with the exception of its rock-bound portions,

[1] From Lewes Levels to Chichester Harbour, and on to Hurst Castle, the coast exhibits signs of undergoing elevation at the present day. The coast of the Isle of Wight, opposite, seems, on the contrary, to be suffering depression; whilst the back of the island exhibits some curious signs of local oscillation. (Godwin-Austen.)

the entire coast of South Devon is engirt with Submerged Forests.

Peat.

Peat is an accumulation of vegetable matter varying in composition, but often formed to a large extent of the Bog-moss (*Sphagnum palustre*).

The whole of this matter is in some stage of decomposition. Near the surface the substance is light coloured and spongy, and the vegetable remains are but little altered; deeper down it is brown, dense, and decomposed; at the bottom it is black, and the peat becomes earthy in its texture.

The Bog-moss continues growing upwards from the points of the shoots, while decay is advancing in a similar manner from their lower extremities, thus forming a thick close mass of vegetable matter, which rots below as it increases in height.

When peat accumulates on a clayey surface abounding in springs, the water sometimes oozes out beneath the peat, and between it and the natural soil in such quantities as to raise up the layer of peat so that it floats.[1]

Peat beds vary in thickness from a few feet to 20 or 30 feet. The peat is largely dug for fuel, being cut in the summer season and stacked. It holds a large amount of water, but the slowness with which it parts with it is a great hindrance to its being largely worked.

Peat is sometimes divided into Hill-peat, Bog-peat, &c., according to the situation in which it is found, and the conditions under which it has been formed, whether on mountain sides, in marshes, forests, lakes, or near the sea.

Peat-bogs are not uncommon on our hills, in North

[1] See article on *Peat* in Ure's Dictionary. Peat is well known to store up water on mountains.

Wales; in Derbyshire, Kinderscout, &c.; in Somersetshire, Black Down (Mendip), also East Harptree; and on the old Forest grounds of Dartmoor (Tavistock, &c.) and Woolmer.

These bogs depend in great measure on the dampness of the air, and the growth of Heather and Bog-moss.

Professor Buckman discovered peat in the bed of the Chelt, near Cheltenham, in which trees occurred with their roots still standing. The formation of peat was doubtless caused by the trees falling across the stream and damming up the water, which then became a peat-bog.

Peat is very largely dug in the moorlands of Somersetshire between Glastonbury and Highbridge. Some of these beds have been worked for fuel from the time of the Romans, and probably earlier, while others are of more recent formation. (See p. 330.)

The peat-moors, or Turbary lands, as they are called where portioned out and appropriated for digging turf for fuel, have an irregular distribution. The peat, which in places is 14 or 15 feet thick, and is sometimes separated by partings of clay, is due largely to the growth of the common sedge (*Carex*), whence Sedge Moor derives its name.

The Rev. W. Phelps has pointed out the formation of the peat in the wet marshy ground, where stagnant water has accumulated. Reeds and rushes spring up above the surface of the water, at which point water weeds will grow, and collecting together soon form a tolerably sound stratum, sufficient as I have been informed to bear the weight of a water rat. This stratum in time sinks, and the process of growth and subsidence is repeated annually until a spongy mass of vegetable matter is formed, upon which heaths and willows will grow.

The following list of plants which have assisted in the formation of the peat in this district was kindly given to me by Mr. Alfred Gillett:—Cotton grass (*Eriophorum*), Bull-

rush (*Scirpus lacustris*), Willow herb (*Epilobium angustifolium*), Sedge (*Carex*), Bog moss (*Sphagnum palustre*), *Erica*, Bog myrtle; and amongst the ferns, *Osmunda regalis*, *Lastrea thelypteris*, and *Pteris aquilina*. It contains also the Sea Wrack (*Zostera marina*).[1] In the Fenland and Bedford levels peat is also dug, and it has been found in many places in Holderness and on the shores of the Humber. In Holderness the beds occupy small lacustrine areas. The peat is met with at depths of 30 or 40 feet beneath the surface, and is only 2 or 3 feet in thickness. It is covered with a marine deposit of silt and clay. (See p. 332.)

Mr. G. H. Morton has described several Peat-beds in the neighbourhood of Liverpool; the lowest bed is 9 feet below low-water mark of spring-tides. (See p. 329.)

Soils.

Soils present great diversity in their constitution. In treating of them we have to treat of earths which form an irregular covering over the greater part of the country, and to do so in detail would require a volume in itself. They are intimately connected with the last denudations of the country, and with the present wearing action of frost, rain, and rivers, combined too with the deposit from organic agencies.

Among the soils there are those of a clayey, loamy, sandy,

[1] *Zostera*. Marine herbs usually growing in shallow water near the edges of the sea, their long rooting stems creeping along in the sand or mud, and sending up slender erect branches, bearing long narrow grass-like alternate leaves, sometimes forming such dense masses as to impede the passage of boats. (A. Smith in Maunder's *Treasury of Botany*.)

and gravelly nature, and mould. I shall confine myself to general remarks on them, as the soils of each formation have been alluded to, so far as possible, in the text describing them.

Soils may be considered as due to local causes, and as varying according to the nature of the underlying geological formation, from which they have been most largely constructed—hence the fact that soils vary mainly according to contours. But if we give this restriction to them, we must include among the geological formations the extensive deposits of gravel, sand, and clay, formed during the Glacial period, and subsequently by marine, estuarine, and fluviatile agencies.

In classifying soils they cannot be treated lithologically, nor according to their relative ages; we must consider their origin.

The influence of soils on Agriculture is, of course, all-important, but their fertility is greatly equalized by manuring and draining. Thousands of acres are, says Mr. J. Bravender, at this moment, to all outward appearances fertile, which are not permanently so, but which have been artificially made productive—these if neglected will eventually return to a state of sterility.

Warp and Trail.—In describing the character of the latest superficial deposits, the Rev. Osmond Fisher has treated of the 'warp of the drift,' so called by Mr. Trimmer.

This warp or general surface soil is influenced in its character by the stratum on which it rests, but at the same time often contains ingredients which cannot have been derived from it.

Mr. Fisher has observed that the subjacent stratum, wherever it is of a soft nature, is worn into furrows and hollows, and he has found that cylindrical pits and pipes are generally confined to soluble beds, and that the normal

form of the cavities in clays, sands, and gravels, is that of troughs or furrows.

The materials which fill these furrows he calls 'trail,' and it is noticeable that where pebbles occur, their axes, more frequently than not, deviate from the horizontal position.[1]

He remarks that the contents of these furrows have contributed to form the warp, and thus we see why the surface-soil sometimes varies so remarkably over limited areas.

The furrows are the tool-marks of the last agent which moulded the surface of the country.

Clay-with-flints.—Amongst the Local Soils we may include the Clay-with-flints, which consists of stiff brown and red clay containing large unworn flints, and at its base displaying generally a few inches of black clay with black-coated flints. Occasionally pebbles of flint, quartz, and other rocks, occur in the deposit, due to some former capping of gravel or of Tertiary beds which has been denuded.

This deposit may be said to be confined to the Upper Chalk tract, as its formation is considered to be due to the dissolution of the Chalk by water holding carbonic acid, whereby the flints and earthy matter were left. It requires also the addition of some of the Tertiary or Post-Tertiary clays to account for the mass of clay that is frequently a large constituent of it. On the surface the flints are much broken up by natural agencies and by the plough, and frequently the fields exhibit a soil of little else than broken flints, so that one could hardly fancy that anything could grow in such places, but good crops of turnips and mangels are obtained.

The flints are frequently picked off, but they soon 'grow' again, if, indeed, any appreciable difference is made.

Sometimes the Clay-with-flints stretches over the margin

[1] In sinking through mud the effect of friction would be to place the pebble on end, while the same result would probably take place from the action of frost and thaw on loamy soils containing pebbles. (Fisher.)

of the Upper Chalk resting on the Lower division. In such cases we may look upon it as a residuum of the Upper Chalk which formerly existed there. Again, in South Devon it appears to rest in places on the Upper Greensand; here, however, as Mr. Whitaker has pointed out, the Chalk-with-flints overlaps the Lower Chalk, and the consequent nearness of the Chalk-with-flints to the Greensand helps to explain the occurrence of the great deposits of flints on the hills of the latter in Devonshire. (See p. 316.)

The Clay-with-flints lies very irregularly on the Chalk, filling pipes, so that sometimes bare Chalk appears in one place, whilst a clayey deposit twenty or thirty feet in thickness may occur close at hand. It is also noteworthy how trifling a depth of soil serves to hide the Chalk in a field when hard by a pit shows scarcely a trace of any superficial covering on the rock. Where the pipes penetrate obliquely into the Chalk, the section in the face of a cliff or quarry sometimes shows merely a circular pocket some way below the surface.

Mould.—The formation of mould or humus is due to the decay of vegetable matter, and to meteoric influences, assisted very largely by earth-worms building up a soil as it were by the material ejected from them, as first taught by Darwin.

Terraces.—'Parallel Terraces,' linchets, or ridges, are not uncommon on the slopes of the Chalk, Oolitic, and Liassic escarpments, and on the outlying portions of these formations.

Such terraces occur on Brent Knoll, near Yeovil and Crewkerne in Somersetshire, &c.

Some authors have attributed them to marine action, but there is not the slightest evidence to support such a notion, which is indeed refuted by the varying inclination and distribution of the ridges.

They are in many instances due to land-slips, and in others are due to an accumulation of rain-wash.

Mr. Scrope has pointed out that such ridges would be rapidly formed when in early times (on the arable Common-field system) nothing was more usual than for the owner or occupier to possess and cultivate several distinct strips or breadths of land separated from one another by the lands of others. Each upper cultivator will naturally have taken care not to allow the soil of his strip to descend to fertilize his neighbour's below, and by forming boundary furrows with a slight ridge of soil between, he would pave the way for a bank of earth which in the course of years increases into a linchet several feet in height.

Grey Wethers.[1]

Scattered here and there over the southern and south-eastern parts of England are blocks of saccharoid sandstone, called Druid Stones, Sarsen (or Sarsden) Stones, and Grey Wethers.

Their occurrence is most conspicuous in Wiltshire on the Downs of Marlborough, &c., and in Berkshire.

Many of the blocks are twelve or fifteen feet across, and four feet in thickness.

[1] Conybeare identified the large stones of the second and outermost circles of Stonehenge (trilithons) with the Grey Wethers. The smaller stones in two of the inner circles he regarded as Greenstone probably from Ireland. Prof. Ramsay has stated that they are certainly not drifted boulders, and do not resemble the igneous rocks of Charnwood Forest; and without asserting that they came from Wales or Shropshire, he observes that they are of the same nature as the igneous rocks of part of the Lower Silurian (Cambrian) region of North Pembrokeshire, of Caernarvonshire, and of the Llandeilo flag district of Montgomeryshire, &c., west of the Stiper Stones. The so-called altar-stone is a slab of felspathic hornstone, a rock plentiful in the districts above cited.

They are used for gate-posts, walls, farm-buildings, paving, and road-metal.

As Prof. Ramsay has remarked, it is clear that they are only the fragments of a stratum which had a very wide range, which there is reason to believe, along with other Eocene strata, spread over the Chalk Downs of the west of England.

Mr. Whitaker considers that such loose blocks may have come from different Tertiary formations, sometimes from the Reading Beds, or from the basement-bed of the London Clay, or the Bagshot Beds.

North-west of High Wycombe the brick-earth contains masses of greywether sandstone, which are worked for road-metal, paving, and building.

Small flint-pebbles sometimes occur in them, and sometimes large blocks of puddingstone (Hertfordshire puddingstone) are strewn about in the same way as the sandstones.

Near Sidmouth large blocks of a siliceous breccia are met with, and pebbles of the same rock, called the Sidmouth pebbles, are picked up on the beach and polished.

Chapter XII.

IGNEOUS AND METAMORPHIC ROCKS.—MINERAL VEINS.

IGNEOUS AND METAMORPHIC ROCKS.

The subject of the Igneous Rocks, like that of Palæontology, would require a special volume, and by one thoroughly conversant with the subject, in order to illustrate it with justice. While the specific determination of a fossil would often require careful indoor scrutiny, and comparison with many other specimens or figures, so for the precise determination of most Igneous rocks microscopic and chemical investigation is needed. Their study has, indeed, become a separate branch of inquiry in itself, and there are few geologists now-a-days who would venture to express opinions concerning a series of Igneous rocks, or even to assign to them names, without first subjecting them to such close examination.

Both Igneous and Metamorphic Rocks may be of any age. The old notion that Granite was always the fundamental rock has long since been exploded. The intrusion of Igneous rocks often produces metamorphism in the contiguous sedimentary deposits, while again the influence of heated waters produces alteration (by decomposition and molecular re-arrangement) in the rocks through which they pass. As our sedimentary strata were originally derived from the old Igneous rocks which formed the earliest land, so do they contain to some extent similar chemical ingredients, and it is easy to understand how in some cases the metamorphism of certain strata should result in molecular changes which

would produce a rock similar to one directly of igneous origin.[1]

Through the kindness of my friend and colleague, Mr. Frank Rutley, I am enabled to give the following condensed account of the Igneous and Metamorphic Rocks.

Metamorphic Rocks.—Sedimentary deposits which have undergone any very marked physical or chemical change are usually spoken of as 'Metamorphic Rocks,' but it is often difficult to define their precise claim to this name, since some, in which the alteration is but an incipient one, would not be generally termed metamorphic, while others, in which the same processes have produced a more strongly developed change, would, by many Geologists, be regarded as fit recipients of the title. As a rule, rocks which have undergone any more or less definite alteration from the contact or proximity of heated masses of eruptive rock are considered to be metamorphosed.

Chlorite Schist, Mica Schist, Talcose Schist, Schorl Schist, Hornblende Schist, Gneiss, &c. &c., are generally regarded as Metamorphic rocks.[2] Most of these schists or slates contain quartz or sandy matter which usually forms fine folia separating the other mineral components, so that the rock is frequently made up of thin but more or less distinct layers which differ in mineralogical composition. This differentiation into layers of dissimilar character is termed foliation. Foliation may occur in eruptive rocks as well as in those which are regarded as metamorphic, and planes of foliation do not, therefore, always represent planes of bedding.

Eruptive or *Igneous Rocks.*[3]—These rocks have resulted from the solidification of molten matter which has been forced upwards from great depths in the interior of the earth, and has either risen through pre-existing fissures, in which case it forms dykes, or it has been intercalated between beds of sedimentary rock, or has formed large irregularly shaped bosses. Again, it may have reached the earth's surface, and have passed out of a volcanic vent either in the form of a lava flow or the matter

[1] Mr. David Forbes proposed the name *Ingenite* (signifying created within or below) for the granitic, metamorphic, and igneous rocks; and *Derivate* for all sedimentary, subaqueous, and subaërial accumulations, since directly or indirectly they are all derived from the destruction of the former.

[2] These rocks are sometimes termed 'Hypozoic' when they occur as fundamental rocks beneath fossiliferous strata. The term 'Schist' is usually confined to rocks which have a foliated structure and are capable of being split.

[3] *Trap* is an indefinite term applied to any eruptive rock.

may have been ejected as ashes or lapilli which have been deposited perhaps on a land surface, or, falling upon the water, have subsided as sediment. Molten matter may also be erupted beneath the sea. The Igneous or Eruptive rocks are separated by some petrologists into two groups, which are respectively termed 'Basic' and 'Acidic.' The former group embraces those rocks which contain under 60 per cent. of Silica; those in which the percentage of Silica is greater being classed in the Acidic Group. This classification is of course a purely arbitrary one.

The minerals which usually enter into the composition of rocks which contain over 60 per cent. of Silica are the following:—Quartz, Orthoclastic Felspar, and sometimes Plagioclastic Felspars, such as Oligoclase and Albite. Micas, either Potash Mica (Muscovite) or the Magnesian Micas (Biotite and Phlogopite), and occasionally Lithia Mica (Lepidolite). Minerals of the Amphibole Group, such as Hornblende, Actinolite, Smaragdite, &c. Epidote Schorl, Apatite, Sphene, Garnets, Talc, Pyrites, Magnetite, Titaniferous-Iron, &c., are often present. Epidote, Pyrites, Magnetite, Limonite, Talc, Serpentine, Steatite, Chlorite, Kaolin, &c., &c., which are of frequent occurrence, have mostly been formed subsequently to the consolidation of the rocks in which they are found: they cannot therefore be regarded as normal components of those rocks, except perhaps in a few instances, but have resulted from the alteration of some of the original components, or from the infiltration of fresh substances in solution. Their secondary origin is most clearly discernible when they occur as pseudomorphs after definitely developed crystals of other minerals. Such pseudomorphs are of frequent occurrence in many eruptive rocks, but are often so minute that in the absence of microscopic examination they would evade detection.

The minerals which most commonly occur in those eruptive rocks which contain less than 60 per cent. of Silica are the following:—

Plagioclastic Felspars; including Oligoclase, Albite, Anorthite, and Labradorite, all of which crystallize in the triclinic system. Leucite, Nepheline, Augite, Diallage, Hypersthene, Olivine, Hauyne, Nosean, Apatite, Magnesian Micas, Chalybite, Magnetite, Titaniferous-Iron, Hæmatite, Limonite, Pyrites, Oxides of Manganese such as Pyrolusite, Psilomelane, Wad, &c., Serpentine, Steatite, Greenearth, Chlorite, Calcspar, Aragonite; Zeolites such as Mesolite, Stilbite, Heulandite, Analcime, Natrolite, Scolezite, Thompsonite, Phacolite, &c., &c. Chalcedony and Agates frequently form geodes in the vesicular cavities of some volcanic rocks.

In sedimentary rocks which have undergone subsequent alteration from the contact or proximity of eruptive masses, the most commonly occurring minerals are the following:—

Garnets, Staurolite, Andalusite, Chiastolite, Kyanite, Chlorite, Mica, Talc, Steatite, Calcspar, Quartz, Magnetite, Pyrites, &c.

There are some rocks with a schistose structure, and often exhibiting foliation, which it is difficult to regard as eruptive rocks, and to which it is equally difficult in all cases to assign a sedimentary origin, since some are at times seen to graduate into truly eruptive, and others into rocks of an unquestionably sedimentary character. And there are other schistose rocks which have no doubt been originally ejected from volcanic vents in the form of fine ashy material and lapilli, which also have a sedimentary character due to the assorting and deposition of these materials in waters once adjacent to the seat of volcanic activity: such rocks consequently possess affinities partly to eruptive and partly to sedimentary rocks.

Hornblende Schist for example comes under the first clause, as it is sometimes seen to pass into Diorite.

Mica Schist may be taken as an example illustrative of the second clause, as it is often seen to pass into ordinary slates; while Basalt-Tuff, Apharite-Tuff, &c., may be considered fair instances of matter of eruptive origin deposited as a sediment.

In the present state of knowledge it is therefore *convenient* to group all these Schistose rocks together, although their origin has, no doubt, in many instances differed very widely.

The following lists will serve to give some idea of the general mineral composition and physical character of the rocks of most common occurrence, and for convenience they will be arranged in two groups, the Eruptive and Schistose.

Eruptive Rocks, containing under 60 per cent. of Silica. (Basic Rocks.)

Chief Mineral Components or Lithological Affinities.

A.

- *Dolerite.*—Labradorite, Augite, Magnetite, Titaniferous-iron.
- *Basalt.*—A more compact form of Dolerite.
- *Olivine Basalt.*—A Basalt in which the Augite is replaced by Olivine.
- *Nepheline Basalt.*—A Basalt in which the Labradorite is replaced by Nepheline.
- *Micaceous Basalt.*—A Basalt containing Magnesian Mica.
- *Leucite Rock.*—A Basalt in which the Labradorite is replaced by Leucite.
- *Diabase.*—Plagioclastic Felspar (probably Oligoclase), Augite, Chlorite, Magnetite, and Titaniferous-iron. This rock is regarded by some petrologists as an altered condition of Basalt.
- *Melaphyre.*—A name given to Basalts of Palæozoic and Mesozoic age. Melaphyres do not differ from the more recent basalts, except in the fact that many of the original component minerals have undergone decomposition or alteration.

B.	*Gabbro.*—Plagioclastic Felspar (possibly Labradorite), Diallage or Enstatite, Magnetite, &c. *Hypersthenite.*—A similar rock to the above, but containing Hypersthene instead of Diallage. *Diorite.*—Plagioclastic Felspar, Hornblende, Magnetite, &c. By the term Greenstone, Diorite is now usually implied; formerly, both Dolerites and Diorites were included under the name.

The rocks in the Group marked A. often occur as lava flows as well as in the form of dykes, volcanic pipes or feeders, and bosses. They are consequently of an unquestionably volcanic nature. The rocks in the Group marked B. do not occur as lava flows, but simply as dykes or as bosses. Although they are at times seen to graduate into the volcanic rocks of the Group A., still they do not appear to have ever been poured out as lava flows at the surface, but have probably solidified at considerable depths, and are only now exposed by the denudation of a vast amount of once superincumbent rock. They would therefore be spoken of as Plutonic rocks in contradistinction to the Volcanic rocks which solidified at or nearer to the surface; but both groups have no doubt often originated from the same foci and may be regarded as approximately similar matter, which has solidified under different conditions of cooling, pressure, &c., inducing a difference in physical and mineralogical character.

Eruptive Rocks containing over 60 per cent. of Silica. (Acidic Rocks).

Chief Mineral Components or Lithological Affinities.

B.	*Granite*[1]	Orthoclase (sometimes Plagioclase), Mica (sometimes Potash Mica, sometimes Magnesian Micas, and frequently both), Quartz. Schorl, Magnetite and Pyrites, &c., &c., often present.
	Syenitic Granite.	A rock similar to the above, except that it contains Hornblende, often in considerable quantity. This rock is frequently designated Syenite.
	Syenite.	Orthoclase and Hornblende.
	Granulite or *Leptynite.*	Orthoclase and Quartz. It frequently has a foliated or fissile structure, and hence is regarded by many as a metamorphic rock, and is classed with those rocks which present a schistose character.

[1] The red or grey colour usually depends upon the colour of the felspar.

	Felstone.	Orthoclase and Quartz, occurring as a fine admixture, the separate minerals not being discernible by the naked eye, and scarcely by microscopic examination. Such a substance is termed felsitic.
	Felspar Porphyry.[1]	A felsitic matrix, containing distinct crystals of Orthoclase.
	Minette or Mica Trap.	A felsitic matrix, containing crystals of Magnesian Mica and small Orthoclase crystals, usually with some Magnetite or Titaniferous Iron, &c.
	Quartz Porphyry.	A felsitic matrix, containing distinct crystals of Orthoclase and Quartz. (Elvan.)
A.	*Gneiss.*	A foliated rock, having the same mineral composition as granite. It frequently graduates into sedimentary rocks, and hence is regarded as a metamorphic rock.
A.	*Phonolite.*	Orthoclase (Sanidine), Nepheline, Hornblende, Pyrites, &c. Hauyne, Nosean, Augite, and Plagioclastic felspar often present.
A.	*Trachyte.*	Sanidine and Plagioclastic felspars, Hornblende, Augite, and Magnesian Mica—sometimes Tridymite.
A.	*Pitchstone.*	Variable in composition, sometimes containing more and sometimes less than 60 per cent. of Silica. As a rule Pitchstone approximates to the felspars in composition. It often contains felspar and magnesian mica, crystals and microliths of augite, and other minerals. On analysis Pitchstones afford a considerable amount of water.
A.	*Obsidian.*	A more vitreous condition of Pitchstone; it seldom incloses any minerals.

The rocks in the group marked B. are called Plutonic, since they have originally solidified at a considerable depth from the surface. Some of them form large tracts of land, bosses, and dykes. Others occur only over limited areas.

The rocks in the group marked A. are clearly Volcanic, since they occur not merely as bosses and dykes, but also as lava flows.

As with the rocks in the first table, so also with the two groups in

[1] *Porphyries* are generally known by the name of the larger disseminated crystals.

this: they probably graduate into one another, and have no doubt often originated from the same deep-seated sources, although the different depths at which they have solidified have exercised an important influence on their physical and mineralogical characters.

Schistose Rocks.

These rocks have a schistose or fissile structure, splitting more or less regularly in planes parallel either to bedding, cleavage, or foliation. In many instances they exhibit a foliated structure, and where this is the case the rock usually splits in directions approximately coincident with the planes of foliation.

In cases where the rock has originally been deposited as a sediment, the foliation may coincide either with planes of bedding or with planes of cleavage; but it should be borne in mind that planes of foliation do not *necessarily* imply the existence, or the former existence, either of planes of bedding or of cleavage planes, although they very frequently do so.

The following are some of the most common schistose rocks:—

Volcanic Ashes.[1]—In these the mineral components may sometimes be identified with comparative ease, but they are frequently composed of very fine fragments or flakes, which in the main consist of felspathic material, the species of the felspar being occasionally undeterminable, and probably, in many instances, mixed. Fragments of Hornblende, Augite, &c., &c., are often present. These rocks are sometimes well cleaved, and afford good roofing slates. Their minute structure and precise mineral composition have as yet been little investigated. Such ashes may have been ejected from a terrestrial or a subaqueous crater, and in the former case may have been showered down on a land surface or have been deposited under water as sediment.

Basalt Ash or *Basalt Tuff.*—This rock has much the same mineral composition as basalt. Indeed we may regard it as basaltic matter ejected in the form of ash and lapilli, instead of having been poured out as a lava flow. In some lava flows it is possible that cleavage may have been superinduced, and so have lent a schistose character to the rock, in which case the fissile structure would serve rather to screen than to elucidate its origin.

Greenstone Ash.—Much of the rock called Greenstone Ash may probably be safely referred to the above. The term, however, as

[1] The terms Agglomerate and Volcanic breccia are sometimes used for these rocks.

formerly used, was not erroneous, since Basalt and Diorite were then included in the term Greenstone.

Aphanite Schist.—A fine-grained rock of eruptive origin, with a fissile structure. This fissile structure may imply lamination, and favour the supposition that the rock originated as ashy matter, and was deposited under water. On the other hand it may imply cleavage. The affinities of Aphanite Schist are probably basaltic. It is an ill-defined but a vague and useful term. The same remark may apply equally to the expression Volcanic Ash. No serious exception can, however, be taken to the use of these terms until the minute structure and mineral constitution of these rocks are better understood.

Hornblende Schist.—The components are for the most part Hornblende and Quartz, often showing a foliated arrangement, but sometimes the two minerals have crystallized out very irregularly, and occasionally the quartz is very poorly represented, or is totally absent, in which case the rock becomes Hornblende Rock.

Schorl Schist.—A foliated rock composed of Schorl and Quartz.

Mica Schist.—Often foliated, composed mostly of mica and quartz. The mica is generally Muscovite, but sometimes it is a Magnesian Mica. Occasionally felspars occur, in which case the rock becomes gneissic in character, and may even pass into true gneiss. Garnets are common in Mica Schist. Passages have been observed from ordinary slate, &c., into it: it is therefore spoken of as a Metamorphic rock. This remark may apply to several of the other Schistose rocks mentioned in this list.

Talc Schist.—Often foliated, composed mainly of Talc and Quartz. When felspathic matter is present, it passes into Protogine Gneiss. Garnets, Actinolite, Chlorite, Pyrites, &c., are frequently present. As in the case of Mica Schist, passages from this rock into Slate, &c., have been observed.

Chlorite Schist.—Sometimes foliated, and composed mainly of Chlorite, with some quartz, and frequently with some felspathic, micaceous, or talcose material. Magnetite, Pyrites, and Chalybite are also of common occurrence. It sometimes passes into Serpentine, Talcose Schist, Mica Schist, &c.

Serpentine.—Chemical composition, Hydrous Silicate of Magnesia. This rock may represent a very highly altered condition of some rock rich in magnesia. Still it is equally possible that soluble magnesian salts may at times have been infiltered into rocks whose original constitution was very different, and which may have contained little or no magnesia. Serpentine often contains Chromic Iron, Garnets, and other minerals. It sometimes passes into Chlorite Schist, Talc Schist, &c., &c. In many eruptive rocks minerals,

such as Olivine, Augite, Hornblende, &c., have undergone considerable change, and are now only represented by pseudomorphs of Serpentinous material.

The vesicular structure, so common in some rocks, occurs almost exclusively in those which have been poured out as lavas or ejected as lapilli, or, at all events, the structure is not exhibited in rocks which have solidified far beneath the earth's surface (Plutonic Rocks). Vesicular structure is due to the presence of bubbles of gas, steam, air, or fluid, forced into the molten, pasty mass, either prior to or during ejection or emergence from a volcanic vent, or it is due to the development of steam by the passage of heated rock over a damp surface, or it is caused, possibly, even by the actual disengagement of gases generated by the decomposition of substances contained within the rock itself. Minute cavities containing gases and fluids occur, however, in some of the minerals composing Plutonic, as well as in some of those which compose Volcanic rocks. These are, as a rule, purely microscopic in dimensions, and do not impart a vesicular character to the rocks in which those minerals occur. The cavities in Pumice are elongated vesicles, and the vesicular structure is sometimes well developed in Basalts. Vesicles in a rock are often filled by substances such as Calcspar, Greenearth, Zeolites, &c., which have gained access to their present tenements by infiltration in solution. Rocks spotted with such filled-up vesicles are spoken of as amygdaloidal, this adjective being prefixed to the name of the rock (*e.g.* Amygdaloidal Dolerite). A somewhat similar structure may, however, result at times from the segregation of certain minerals in a rock during its solidification. Still, as a rule, the different origin of these structures is clearly discernible.

FRANK RUTLEY.

In the following remarks it is proposed to deal with our Igneous and Metamorphic rocks in only a very general way.

If we study a geological map of England and Wales we find a large mass of igneous rock, termed basalt, on the borders of the Cheviot Hills in Northumberland, as well as several isolated patches of the same rock.

The Cheviot Hills are partly formed of this rock and porphyry, and partly of sandstone and conglomerate of Lower Carboniferous age.

The Great Whin Sill, which forms so striking a feature on our geological maps, is a mass of intruded basalt, which usually forms the boundary between the Carboniferous (Scar) Limestone and the Yoredale rocks in Teesdale, along the Pennine escarpment, extending to Northumberland. It consists of white felspar and dark green augite, and is generally about 24 feet in thickness, but is as much as 120 feet at Alston Moor.

Messrs. Topley and Lebour have demonstrated that the rock is intrusive, and that it has been forced in a molten state through the neighbouring strata, long after their deposition and partial consolidation. Throughout Northumberland they say that the rock is not so constant in position, and that it frequently alters the beds above it as well as those below, and that in numerous instances it can be seen cutting through the strata in a manner that would be impossible if it were a contemporaneous deposit.

Where easily accessible the rock is used as road-metal. Sometimes its decomposition gives rise to a porcelain-clay.

Amongst other dykes are the Hett dyke and Cockfield dyke, which traverse the Carboniferous beds.

Prof. Hull mentions that the beds of coal when approaching these dykes become anthracitic, and ultimately worthless.

The Granite of Wastdale Crag near Shap is thus described by Dr. H. A. Nicholson :—'About four miles to the south of the village of Shap in Westmoreland there occurs a mass of Granite, which has been long known to geologists by the enormous number and wide distribution of the erratic blocks which have been derived from it. It breaks through the highest beds of the Green Slates and Porphyries of the Lake district, and is of comparatively small superficial extent, forming but two elevations of any note, namely, Wastdale Crag and Wastdale Pike. As to the date of its production nothing can be positively stated except that it is certainly

posterior to the formation of the Green Slates, and prior to the deposition of the Old Red Sandstone. It is characterized by the great number and comparatively large size of crystals of pink felspar, which constitute it a porphyritic granite.' (See p. 40, and fig. 4, p. 41.)

There are also the granites of Eskdale and Wastwater, Dufton, those of the Caldew Valley or Skiddaw Forest, and the Syenitic granite of Buttermere and Ennerdale. Some of the granites send out veins into the slates.

There are many volcanic rocks in the Lake District, some of which have been carefully investigated by Mr. J. Clifton Ward. He has stated his belief that the Cumbrian volcanoes were mainly subaërial, since some 12,000 feet of ash- and lava-beds have been accumulated without any admixture of ordinary sedimentary material, except quite at the base, containing scarcely any *conglomeratic* beds, and destitute of fossils. He believed also that *one* of the chief volcanic centres of the district had been the present site of Keswick, the low craggy hill called Castle Head representing the denuded stump or plug of an old volcano.

He has observed that the metamorphism among the Cumbrian rocks increases in amount as the great granitic centres are approached; and that it took place mainly at the commencement of the Old Red Sandstone period, when the rocks must have been buried many thousands of feet deep beneath the Silurian strata, and when probably the Eskdale granite was formed, perhaps partly by the extreme metamorphism of the volcanic series during upheaval and contortion.

Igneous rocks are largely developed in North Wales. According to Prof. Ramsay, west, south, and east of Dolgelly, patches of greenstone have been protruded amid the strata, the irregular forms of the igneous rocks being in some degree due to the contortions of the Lingula Flags, among which they lie.

The Tremadoc Slates are overlaid by great accumulations of volcanic ashes and lava flows, extending in a crescent form round the Lower Cambrian, Lingula, and Tremadoc beds, and forming the heights of Cader Idris, the Arans, the Arenigs, &c. (See fig. 3, p. 39.)

Most of the rocks between Bettws-y-Coed, Moel Siabod, Llyn-Ogwen, and Conway, according to Prof. Ramsay, are the actual equivalents of the slender band of Bala limestone, near Bala, and of the slates and insignificant ashy bands that underlie it.

Moel Siabod and Carnedd Llewelyn show at their summits great masses of greenstone intruded amidst the fossiliferous grits and slates of the Bala formation. Snowdon, Moel Hebog, and Y-Glyder-fawr are formed largely of beds of felspathic porphyry associated with fossiliferous grits and volcanic ash-beds, with occasional intruded masses of greenstone. (See fig. 6, p. 44.)

Nevertheless we must bear in mind, what Prof. Ramsay tells us, that although there are volcanic rocks in the mountains of North Wales, we must not associate the present forms of the hills with the idea that they were old volcanos, for the lake-basins and other hollows are for the most part the result of denudation; indeed, the great features are the result of denudation, influenced by the great disturbances which have affected the whole of the rocks.

Numerous bosses of greenstone occur in the Lleyn promontory in North Wales.

The greenstone dykes which occur in the slate quarries of Penrhyn and Llanberis are considered by Prof. Ramsay to be of later date than the contortions of the strata that produced the cleavage in them, and they are probably Post-Carboniferous.

The Penmaenmawr stone near Caernarvon is a felstone which, from its toughness, forms a valuable paving material.

It occurs as an intrusive mass in the Cambrian (Lower Silurian) rocks near Conway, in Caernarvonshire.

Prof. Ramsay observes that in South Staffordshire, Coalbrook Dale, the Clee Hills, and Warwickshire, there is a little basalt and greenstone, which may possibly be of Permian age, intruded into and perhaps also partly overflowing the Carboniferous rocks in Permian times.

The basalt of Rowley Regis or Rowley Rag is columnar, and was considered by Jukes to be a lava flow during the Coal period. It is largely used for road-mending.

In the Lower Coal Measures of Warwickshire the intrusive sheets of greenstone nearly correspond with the planes of bedding. At Coventry this rock is called Griff stone.

The name Toadstone is applied to the greenstone which is intercalated with the Carboniferous Limestone in Derbyshire.

Syenite (so named from Syene in Egypt) occurs at Malvern and Charnwood Forest.

It appears that both granite and syenite occur at Mount Sorrel. The rock is of a pink colour, and has been worked also at Grooby. Bardon Hill is composed of it.

Prof. Ansted, speaking of Charnwood Forest, has expressed his opinion that the rocks hitherto described as igneous are strictly metamorphic; that the syenitic and porphyritic rocks there exhibited really alternate with the slates, and are strictly contemporaneous; that the whole series therefore is nothing more than a series of altered stratified rocks with few intrusive or trappean rocks.

In Somersetshire some basaltic rocks occur on the Mendip Hills; and at Adscombe, near Nether Stowey, is a compact fragmentary rock, possibly volcanic ash (as suggested by Mr. F. Rutley), which has been worked for building purposes.

At Washfield, near Tiverton, is a peculiar bed considered by De la Beche to have been formed during the accumulation

of the Triassic series by volcanic ejections falling into the water in which the sands and other detritus were being accumulated. The Pocombe stone, near Exeter, comprises a compact basaltic rock with included brecciated fragments, and amygdaloid. The Thorverton stone is another igneous rock of a similar kind. Near Newton Abbot there are many exposures of igneous rock amidst the Devonian slates: they appear to be intrusive, and are generally marked by hilly features, the result of their resistance of denudation.

Brent Tor, near Tavistock, is frequently spoken of as the site of an old volcano, but its form, as Mr. Rutley tells me, is evidently due to denudation. De la Beche, however, described the volcanic ashes and cinders met with at Brent Tor, which he regarded as suggestive of a volcano in the vicinity —this would probably have been in Poikilitic times.[1]

Granite is largely developed in Cornwall and Devon. The Cheesewring granite is a light-coloured rock with white felspar. It is quarried under the hill on which the Cheesewring is situated, near Liskeard. This rock was used in the construction of the London Docks, Westminster Bridge, the Thames Embankment, &c.

Granite is quarried at Lamorna, west of Penzance, Penryn, Falmouth, Carn Brea, St. Austell, Par, Hensborough near Lostwithiel, Calstock, Padstow, &c.[2]

On Dartmoor the granite has been chiefly worked at Hey (High) Tor, and near King Tor, Tavistock, &c. It is probably of Permian age, as it alters the Carboniferous rocks which adjoin it, and as boulders of the granite are found in the Triassic breccias and conglomerates on the coast. (See fig. 12, p. 110.)

[1] Red jasper is found in the Carboniferous rocks near Brent Tor.

[2] Mr. J. A. Phillips has stated that the clay slates of Cornwall differ materially in composition, but no rearrangement of their constituents could result in the production of granite.

Granite has been quarried at Lundy Island; the Gannet Stone (Ganiston) is a variety worked on the northern part of the island.

From the *Channel Islands* large quantities of granite are exported, chiefly for use as London road-metal. It is obtained from the quarries of Mont Mado and La Perruque in Jersey, and from Guernsey and the little island of Herm. At Jersey bricks are made from a decomposed igneous rock.

Greenstone is much worked near St. Austell. Mr. J. A. Phillips has pointed out that the so-called 'greenstones' of Penzance are chiefly hornblendic slates.

Porphyritic granite occurs at Lanlivery and Luxullian. The Luxullianite is a porphyritic rock, consisting of large crystals of pink orthoclase-felspar, associated with much schorl, or black tourmaline, and a small quantity of quartz.

This rock was used for the Duke of Wellington's sarcophagus in St. Paul's Cathedral.

Elvan is a term used in Cornwall and Devon for a crystalline rock, generally of a whitey-brown colour, formed of quartz and orthoclase. It occurs in veins or dykes which proceed from the granite, and is often nearly identical with it in mineral composition.

Elvans vary considerably in texture; sometimes they are of a laminated nature. The Killas appears much altered by contact with them, and has in places a serpentine-like appearance.

Elvan rocks have been obtained from the Land's End, from Marazion near Penzance, near Helston, Penryn, Truro, Pentuan (Pentuan Stone), Lanivel, St. Neot's, St. Dennis, Camelford, Okehampton, &c. The Rowborough stone occurs between Plymouth and Tavistock.

Elvan is a very durable stone, and is well adapted for building purposes and for road-metal.

At Carclase, near St. Austell, are the Tin Mine and China

clay (or Kaolin) works. The tin occurs in veins in the decomposed granite or China clay.

This clay is dug out by the miners: it is full of crystals of quartz, and is sometimes called Cornish or Porcelain Clay. It appears to be due to the decomposition of the felspar and mica of the granite. (See also pp. 271, 279.)

'Kaolin or China clay is prepared chiefly in the neighbourhood of St. Austell, in Cornwall, and at Lee Moor, about five miles from Plympton, in Devonshire. The decomposed granite rock is broken out, and is commonly exposed on an inclined plane to the action of a fall of water, which washes it down to a trench, whence it is conducted to catch-pits. The quartz, schorl, mica, and other minerals present are chiefly retained in the first pit, and as the water charged with the clay flows onward it deposits the grosser particles, and eventually the pure and fine clay is deposited in tanks prepared to receive it. These tanks are about 9 or 12 inches deep, and when filled with clay the water is turned in another direction, and the mass allowed to consolidate. The clay is then run into a roofed building, beneath the floor of which hot air circulates freely. Thus the clay is dried perfectly. It is then cut into oblong lumps, and having been scraped to remove dust from the outside, it is sent to the potteries.

'The China clay is now used extensively in our paper manufactories, it is finding a new application in the preparation of the figured papers for walls, and it is used extensively in all our bleaching establishments.

'China Stone is the production of the granite rock which furnishes the Kaolin, but in a less advanced state of decomposition—the felspar still retaining much of its silicate of potash or soda, associated with the quartz and with scales of a greenish yellow talcose substance.

'The Serpentine,—so called from the supposed resemblance of the rock to the skin of a serpent,—which is found

in quantity at the Lizard, is one of the most beautiful of the ornamental stones of this country. The variegated colours on which its elegance depends are usually dark rich shades of red and green, irregularly mingled, and often relieved by white veins of *steatite* or soap-stone. Near to and eastward of Cadgwith a very beautiful variety of reddish serpentine occurs, studded with brilliant laminæ of *diallage*, a silicate of lime, magnesia, iron, &c., allied to augite. Both the serpentine and the associated steatite are essentially hydrous silicates of magnesia. Formerly the steatite, from the "Soap Stone Rock," near Mullion, was sent in considerable quantities to Bristol, where it was used in the manufacture of carbonate of magnesia; and at one period was employed at Swansea in the manufacture of earthenware, but it is no longer worked.

'For purposes of ornament this elegant stone is well adapted, being moderately soft, but not brittle, and therefore easily worked, while it is sufficiently hard to receive an excellent polish. There are few spots around the British coast more beautiful and grand than Kynance Cove near the Lizard, where the serpentine rock, in all its varied hues, is polished by the beat of the Atlantic waves, and, in contrast with the white sands of the shore, is rendered still more striking and characteristic.'[1]

Serpentine is considered as a product of metamorphism, and to be derived from hornblende rock or diorite. (See p. 372.)

De la Beche has remarked that hornblende slate seems intimately connected with the talco-micaceous slates near Poltreath, on the west of Lizard town. It supports the great mass of Lizard serpentine, with an apparent passage of the one into the other in many places.

[1] These notices are taken from Messrs. Hunt and Rudler's Descriptive Guide to the Museum of Practical Geology.

The Clickertor Rock, near Menheniot, is a serpentine with veins of Carbonate of Lime and Chrysolite.

The Polyphant stone of Lewannick, near Launceston, is a metamorphic rock.

In Anglesea the Green (Mona) Marble of Rhoscolyn, Holyhead, is a serpentine.

MINERAL VEINS.[1]

The phenomena of lodes or mineral veins require special treatment, and I need only allude to them briefly.

It is patent to all that the mode of occurrence of lodes is very uncertain; the 'shifts' and 'heaves' which affect the strata in which they occur contribute largely to the uncertainty, while the ores themselves are generally deposited on the sides of such dislocations in the strata. Surface indications are seldom considered very reliable evidences for mineral wealth at a depth.

Mineral veins occur in faults or in fissures or joints of the strata. The ores worked in England and Wales are chiefly those of Lead, Zinc, Tin, Copper, and Iron.

The material forming the greater part of the lode or vein apart from the ore worked, such as quartz or calc-spar, is called the Gangue; the material at or near the outcrop of the lode is called the Gossan; and the wall of the lode is sometimes termed the Capel.

Much of the material forming mineral veins is no doubt due to ordinary aqueous deposition, but in regard to the formation of the metallic minerals much uncertainty exists;

[1] For an account of the Minerals of England and Wales, see Greg and Lettsom's *Manual of the Mineralogy of Great Britain and Ireland* (1858); Hall's *Mineralogists' Directory* (1868); Bristow's *Glossary of Mineralogy* (1861); and Rutley's *Mineralogy* (1874).

heated water is known to convey the soluble salts of some of the metals, but the exact causes of segregation or deposition cannot here be discussed, and it will suffice to say that both chemical and electrical action may have been instrumental in producing our mineral veins.

The traces of metallic ores in the Bath waters are very slight, but Sir Charles Lyell points out that the component elements of these ores may, in the first instance, rise from great depths in a state of sublimation or of solution in intensely heated water, and may then be precipitated on the walls of a fissure as soon as the ascending vapours or fluids begin to part with some of their heat. Almost everything, save the alkaline metals, silica, and certain gases, may thus be left behind long before the spring reaches the earth's surface.

Iron Ores.

The occurrence of iron ore in stratified deposits may be said to be universal, but it is only in particular formations and in limited districts that it can be worked with profit.

Pyrites (Iron pyrites or bisulphide of iron) is not available as a metallic ore, but is used for the preparation of sulphur. In Cornwall it passes by the name of mundic.

The red and brown oxides of Iron are very abundant; these are Hæmatite and Limonite. The former is largely worked at Ulverstone and Whitehaven; the latter particularly in the Forest of Dean.

These ores are largely disseminated in the Triassic strata, and especially in the Dolomitic Conglomerate, whilst at the same time they fill veins and pockets in the Carboniferous rocks, the Mountain Limestone, Millstone Grit, and Pennant Grit.

Spathose iron ore is a mineral whose composition is subject to considerable variation, the carbonates of lime, magnesia, and protoxide of manganese frequently replacing

to a greater or less extent the carbonate of iron. Moreover this carbonate of iron is frequently associated with certain argillaceous impurities which interfere with its crystallization, and give rise to the dark-coloured massive varieties called *clay-ironstones*. These impure argillaceous carbonates,—which are so profusely distributed throughout our Coal-measures, partly as regular seams of variable thickness, and partly as nodular concretions,—constitute the ore which, in this country, yields by far the largest amount of our iron.[1]

The ore known as *black band* is an argillaceous carbonate of iron with some carbonaceous matter.

Spathose Iron ore is worked in the Devonian rocks of the Brendon Hills in Somersetshire, and at Weardale in Durham, &c.

Lead Ores.

Lead mining has been carried on in this country from a very early period. When in the possession of the Romans, many of the lead mines in Wales and England were worked, and considerable quantities of lead obtained, as we may infer from the immense accumulation of slags in Derbyshire, the Mendip Hills, and elsewhere.

The principal lead-producing counties of England are Durham, Northumberland, Cumberland, Yorkshire, Derbyshire, Shropshire, Devonshire, and Cornwall; and in Wales, Cardiganshire, Flintshire, Montgomeryshire, and Denbighshire. Lead ore is also raised in large quantities in the Isle of Man.

[1] Hunt and Rudler. Some clay-ironstones exhibit a concretionary form, called 'cone in cone,' as the seam of ironstone breaks into conical forms with the bases of the cones at top and bottom of the seam, and their apices pointing towards each other. The surfaces of these cones are corrugated by small horizontal fretted wavelets, or ridges, rather resembling those on the outside of some stalactites, and each cone is concentrically enveloped by several coats, the surface of each being similarly corrugated. (Jukes and Geikie, *Manual of Geology.*)

The most important ore of lead is the sulphide called *Galena*. In addition to the lead, of which the purer varieties of galena contain upwards of 86 per cent., silver is often present and extensively extracted.

Carbonate of lead, Cerussite, or white lead ore, is largely used for white paint.

Zinc Ores.

Calamine, or carbonate of zinc, has been raised in Cornwall, in the Mendip Hills, Derbyshire, Alston Moor, Holywell in Flintshire, &c.

Blende, Black Jack, or sulphide of zinc, is found in most of the mines in Cornwall, at Alston Moor, in Derbyshire, &c.

Copper Ores.

Copper is found native in the slate rocks (Devonian) of Devon and Cornwall, and in Anglesea.

It is not unusual to find, in the fissures of the serpentine rocks, masses of native copper.

Copper pyrites, Chalcopyrite, or sulphide of copper, is the ore most largely worked. It occurs in Cornwall, Devon, South Wales, Staffordshire, Lancashire, and Alston Moor in Cumberland.

Malachite, or green carbonate of copper, is valuable as an ore, and when cut and polished it is used for ornamental purposes. It occurs in Cornwall and Cumberland.

Tin Ore.

Tin usually occurs as a binoxide, Tin stone or Cassiterite.

It is worked in Cornwall and Devonshire in the Devonian Slates and Granite. (See p. 380.)

The stream-works, as they are called, in Cornwall, are evidently estuaries in which rounded fragments of tin ore are sufficiently abundant among the gravel which forms the

bottom-bed, to render the laying open of these deposits a profitable speculation.

Gold.

Gold was worked by the Romans at Gogofau west of Llandovery in the Cambrian (or Lower Silurian) Rocks. It is now worked near Dolgelly in the Lingula Flags and older rocks. It has also been found at North Molton in Devonshire.

Manganese Ores.

These include Pyrolusite (Binoxide), Psilomelane (Hydrous peroxide), and Manganite (Hydrous sesquioxide): they occur chiefly in Cornwall, Devon, and Somerset.

Plumbago.

Graphite, Plumbago, or Black Lead, occurs at Borrowdale and Bannerdale in Cumberland, in Cornwall, and in the Isle of Man. It is nearly pure Carbon.

It is used in the manufacture of black lead pencils, crucibles, &c.

CHAPTER XIII.

DENUDATION AND SCENERY.[1]

THE subject of the origin of our scenery is in one sense immediately associated with the agencies now in action, and it might be said to belong more properly to a treatise on Physical Geography. Nevertheless the features of our country are due to causes that have acted from the earliest geological times. They are due to disturbances and denudation that have taken place in different ages. Although very little observation will prove that our hills and valleys are due essentially to the removal of material or to Denudation, yet the varied arrangement of our rocks, the disturbances defining the dip of the beds, the faults, fissures, and joints by which they have been affected, and their different textures, have all aided or modified the effects of the denuding agents, so that it is not so easy to determine the particular causes that have produced and modified the scenery.

Thus, in studying the causes and effects of Denudation, we must be prepared to acknowledge help on all sides. Atmospheric action—rain and frost—assists the sea in wearing away our cliffs; the former produces the landslip, the sea or river carries it away. A sun-dried crack allows water to

[1] Some of these notes were published by the writer in an article on the Origin of our English Scenery, *Popular Science Review*, Jan. 1875. The subject has been largely treated by Col. Greenwood, *Rain and Rivers* (2nd Edit., 1866); Mackintosh, *Scenery of England and Wales* (1869); Ramsay, *Physical Geology and Geography of Great Britain* (3rd Edit., 1872); and Kinahan, *Valleys and their Relation to Fissures, Fractures, and Faults* (1875). See also many articles in the *Geological Magazine*.

penetrate; frost, by its expanding action, severs the rock. Now rain, rivers, and sea, take advantage of old cracks and joints in their denudation, just in the same way as the quarryman does: such cracks and joints do to a certain extent, and faults often to a great extent, *modify* the form of our valleys.

Elevation, too, must have brought rocks deposited under water, to their present level above it.

The effects of the sea are patent to all in the gradual ruin of our cliffs and waste of our coast line. The effects of rivers are to be estimated best by the amount of solid matter which they bring down with them; while the action of rain is partly combined with that of rivers, and is partly of a chemical nature: the carbonic and other acids which it imbibes in its course through the atmosphere and the soil assisting largely to form caverns, and displaying their action in a lesser degree in the fantastic shapes and hollows so often seen on the exposed surfaces of limestone and other rocks.

The effects of ice are clearly traced by the presence of phenomena similar to those produced in countries where glaciers now exist.

Thus, in England and Wales, all these denuding agents have done and (with the exception of ice) are still doing considerable work; but while rain and rivers act silently and almost imperceptibly, the sea is ever encroaching in a conspicuous manner on our coasts. Those, however, who are continually travelling about in the country will notice the results of subaërial denudation[1]—the effects of heavy rains and local floods, the occasional slips of earth on the sides of hills; and these, though comparatively feeble in the results produced, are yet very important when multiplied by years. In past

[1] This term is generally applied to denudation by atmospheric agencies, rain and rivers. Mr. G. H. Kinahan uses the term Meteoric Abrasion.

times rain-fall may have been greater, perhaps very much greater at particular periods, as Mr. A. Tylor has advocated. Those also who have resided twenty or thirty years in one district have noticed considerable changes in the outline of the cliffs and rocks, whether by marine action or by rain and rivers. The waste of the cliffs by sea-action, aided by weather, is, however, far more perceptible than the inland subaërial waste. This is very conspicuous on the Norfolk coast, but even here the atmospheric agents are the prime causes of the ruin of the cliffs.

It may be thought that the effects of the sea have been rather neglected in this sketch, but it is by no means wished to detract from its power. The shape of the British Isles is in a great measure, although not entirely, due to its action: the irregularities being for the most part produced by the alternation of hard and soft rocks, the former constituting the headlands, the latter the bays. The effects of submergence have in some cases allowed the sea to encroach and modify valleys previously formed by river-action. This process, as will be noticed, tends to check the denudation by rivers; while, on the contrary, a fact pointed out by Prof. Geikie, as the land rises the cliffs are removed from the reach of the breakers, and a more sloping beach is produced on which the sea cannot act with the same potency as when it beats against a cliff-line; and this action promotes subaërial denudation.

Islands have been formed by denudation and depression, and there are some regions which, although they retain the name, are no longer islands, and have been united to the mainland by the accumulation of material, by elevation, or by artificial barriers.

Prof. Ramsay believes that the Isle of Anglesea was separated from the mainland by a great glacier or ice-sheet which came from the north-east: but the effects of faulting and

depression, combined with the action of the sea, have had considerable influence on the form of the Menai Strait.

The Isle of Purbeck is not really an Island, being only isolated by streams. Portland too is connected with the mainland by the Chesil Bank. Barry and Sully Islands are connected with the mainland at low-tide.

Thanet, Ely,[1] and Axholme in Lincolnshire were islands in comparatively recent times, as also the little isle of Athelney in the Somersetshire moorlands, and perhaps also Glastonbury Tor—the old Isle of Avalon.

Sheppey, Hayling, and Thorney Islands were probably connected with the mainland in recent times. The Isle of Wight has doubtless been formed by denudation and depression.

It would, however, occupy too much space to attempt to discuss the origin of each of our many islands and islets.

Nor need we dwell upon the particular method of formation of each bay and headland, for a glance at a Geological Map will indicate the relations of the rocks to the outline of the coast.

The origin of the Bristol Channel would seem at first thought to be a very simple subject. It would seem to be due to the widening of the mouth of the Severn by marine action—the headlands and bays being due to the alternation of hard and soft strata. And there is no doubt but that the present form of the coast-line is mainly due to the action of the sea on rocks of varying hardness. Caermarthen Bay, Oxwich Bay, and Swansea Bay are excavated in the Coal Measures, and between Aust Cliff and Porlock Bay the Triassic marls and sandstones have been most easily denuded; while the harder Carboniferous Limestone and Devonian rocks stand out more boldly.

[1] The Isle of Ely is said to have been an island 800 years ago, at the time of the Norman Conquest.

But were we to discuss all the phenomena connected with the formation of the Bristol Channel, we should have to deal with all the changes which the geological history of the bordering rocks would teach.

In treating of the Inland Features and their method of formation, we must deal with the subject in a large way, and at the same time we must not only study the modifying causes now in action, but those which have affected the area since the earliest deposits of which we treat were laid down. It will then be seen that the scenery is due to many causes, partly to the method of accumulation of the strata, to subsequent tiltings and disturbances, and to erosion at various geological periods. Thus the three main factors are Deposition, Denudation, and Disturbance: Deposition has produced the material, Denudation has carved it into shape, and Disturbance has defined the mode of Denudation.

The relations of hill and dale to geological formations are so generally marked that to the geologist a geological map gives a very good idea of the physical features of a country.

The connection between scenery and disturbance is very varied.

Synclinals, as pointed out by Mr. Topley and others, are apt to resist denudation, while anticlinals, from their being broken up or fissured at the summit, would be readily acted upon by atmospheric denudation. Hence (says Prof. Geikie) that which in geological structure is a depression, has by denudation become a great mountain, while what is an elevation has been turned into a deep valley.[1]

[1] The valley of Kingsclere and Burgclere, in Hampshire, was described by Dr. Buckland as a 'Valley of Elevation,' because it has been caused by the elevation of a long mass of Chalk, attended no doubt by much fracturing, and the subsequent denudation of the beds, so as to expose an inlier of Upper Greensand.

Of what rocks the earliest hills and valleys were formed it is not easy to say, but they must all have belonged to the igneous class, and have been of a more or less crystalline nature. The history of the earth as told by our stratified rocks indicates an incessant change; no new materials are added (if we except the slight additions made by meteoric stones and dust), but all are ever undergoing some change either in form or in combination.

From the greater portion of our rocks being deposits formed in the ocean, it might at first naturally be supposed that the sea was the great agent of destruction. A few moments' reflection will, however, show how erroneous such a conclusion would be, for the greater part of the material worn from the land is carried out to sea by rivers, and there mingled with the marine shells and the sediment due to the waste of the sea-cliffs; so that it would evidently be giving too much credit to the destructive power of the sea, great as it is, to consider all, or perhaps even the principal part of the matter mechanically deposited at its bottom as owing to its wear and tear.[1]

The earlier deposits were upheaved and converted into dry land while other and newer deposits were being formed, partly by their destruction, and owing to repeated elevation and submergence the older rocks have suffered more by denudation of all kinds than the newer. Moreover they have been subjected to great pressure from superincumbent strata subsequently removed, and have been more altered or meta-

[1] Professor Geikie has compared the work done by rain and rivers and that done by the sea. It has been estimated that the Mississippi carries annually to the sea about 812,500,000,000 lbs. of mud. Allowing the sea to eat away a continent at the rate of ten feet in a century, and that on a moderate computation the land loses about a foot from its general surface in 6,000 years, then before the sea could pare off more than a mere marginal strip of land, between 70 and 80 miles in breadth, the whole of Europe would be washed into the ocean by atmospheric denudation.

morphosed by contact with igneous rocks than the newer strata, and from these causes their texture is or has been continually hardening, and therefore the older rocks as a rule are of a more stony or slaty nature than the newer, which in most cases have suffered little from volcanic or igneous action.

These facts will help us when we come to consider the varieties of scenery. The older rocks have been more subject to denuding agents than the newer, and yet as we now see them they are most capable of withstanding the effects of denudation. Beds of a clayey nature, or soft sandstones, are more easily worn away than slate, limestone, or grit, and consequently the latter form ridges, escarpments, and the summit of table-lands, while the former are exposed in hollows and valleys. The texture of the rocks has thus an important influence on scenery, apart from age.

The dip of the strata has likewise affected the configuration of our land. In this respect the angle of repose is important, and may well be observed in our railway-cuttings.

In studying the causes and effects of the Denudation of England and Wales, we may divide the subject into two parts: (1) that which has affected its grand features; and (2) that to which its minor features are due. In the former case we may see that the character of the scenery depends most on the age of the geological formations; in the latter case the lithological characters of the different rocks come most prominently into play.

The grand features are due firstly to great lines of elevation, and secondly to the effects of denudation.

In noticing the effects of elevation and the age of the rocks, we may observe that the oldest Palæozoic rocks form as a rule the most elevated scenery, as in North Wales and the Lake District. The Old Red Sandstone forms undulating scenery of considerable elevation, as in Herefordshire, the

Mendip Hills, &c.; while the Devonian rocks of Devon and Cornwall (which may be partly of Carboniferous age) form equally bold scenery, and by the nature of their strata often rival in grandeur that of the older slaty rocks. The Carboniferous rocks form scenery that is conspicuously their own: the Mountain Limestone is celebrated for its Combes or Dales, as the counties of Derby and Somerset well instance, whilst the Millstone Grit, Yoredale Rocks, and Coal Measures form hilly and somewhat barren country, often moor-land, as in our Coal districts, in the Peak country, Glamorganshire, and elsewhere.

When we come to the Red Rocks, or those of Permian and Triassic age, which form a belt across the country from Torquay and Sidmouth to the mouth of the Tees, we find a low-lying series of vales which are different in their agricultural character and scenery from the older rocks which bound them roughly on the one side, and the newer on the other. 'The part to the north-west of this line is chiefly Palæozoic ground, often wild, barren, and mountainous, but in many places full of mineral wealth; the part to the south-east of it is Secondary and Tertiary ground, and generally soft and gentle in outline, with little or no wealth beneath the soil. The mining and manufacturing populations are to be found in the former district, the working people of the latter are chiefly agriculturists.'[1]

The lower beds of the Lias and the Rhætic beds form a gentle escarpment above the New Red series, bordered generally by the escarpment of the Oolites[2] which stretches from Dorsetshire by the Cotteswold Hills to the Yorkshire Coast.

[1] Remarked by Dr. Buckland: see Manual of Geology, by Jukes and Geikie, p. 617.

[2] This is used as a general term to embrace what is really a series of minor escarpments, although, looked at in a large way, the Oolites form one striking feature, particularly in the Cotteswold Hills.

The next principal feature is the escarpment of the Chalk forming the North and South Downs, stretching from the Chiltern Hills into Norfolk, and again appearing in the Wolds of Lincolnshire, and Yorkshire.

The Tertiary clays and sands are all of a more or less yielding nature. They form tracts of low-lying and gently undulating country in Hampshire and in the Eastern counties.

The most recent deposits of Alluvium (sediment deposited by existing rivers and estuaries) form tracts of almost level land such as that which borders the Thames conspicuously between London and Tilbury, the Fenland, and the Somersetshire Levels. (See Map.)

In illustration of this subject it may prove useful to give the following classification of Hills and Vales.

HILLS.[1]

A study of the Physical Features of England and Wales taken in connection with the geological structure would lead to a classification of the hills somewhat different to that generally taught on essentially geographical principles.

Thus the Primary or Palæozoic ranges would include the following:—

CHEVIOT RANGE (Carboniferous and Igneous), 2,658.

CUMBRIAN MOUNTAINS (Cambrian and Silurian): Scawfell Pikes, 3,229; Helvellyn, 3,055; Skiddaw, 3,022; Saddleback, 2,847.

CAMBRIAN MOUNTAINS (Cambrian and Silurian): Snowdon, 3,571; Cader Idris, 2,959; Plynlimmon, 2,463.

PENNINE CHAIN (chiefly Carboniferous—extend from the Cheviots to Staffordshire and Derbyshire): Cross Fell (Millstone Grit), 2,927; Whernside, 2,384; Mickle Fell (Millstone Grit), 2,600; Ingleborough, 2,361; Pendle Hill (Yoredale), 1831; Pennygant, 2,270; Kinderscout, Peak district (Millstone Grit), 1,981.

Longmynd (Cambrian), 1,674.

Caradoc Hills (Cambrian), 900 to 1,200.

Clee Hills (Basalt and Coal Measures): Brown Clee, 1,805; Titterstone Clee, 1,750.

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[1] The heights are given in feet.

Wrekin (Igneous, Cambrian), 1,320.
Lickey and Clent Hills (Silurian and Poikilitic), 1,007.
Abberley Hills (Silurian), 900.
Malvern Hills, Worcester Beacon (Gneiss), 1,396.
Charnwood Forest, Bardon Hill (Granite), 852.
Black Mountains, Brecknock Beacon (Old Red Sandstone), 2,862.
Mendip Hills, Blackdown (Old Red Sandstone), 1,067.

OCRYNEAN CHAIN. { *Devonian Ranges*: Quantock Hills (Devonian), Will's Neck, 1,262; Exmoor (Devonian), Dunkerry Beacon, 1,690; Dartmoor (Granite), Yes Tor, 2,050; Amicombe Hill, 2,000; Cawsand Beacon, 1,792.
Cornish Highlands (Granite): Brown Willy, 1,368; Rough Tor, 1,298.

The Secondary or Mesozoic ranges would include:—

North York Moors (Oolites): Cleveland Hills, Burton Head, 1,485; Hambleton Hills (Coral Rag), 1,404; Howardian Hills (Lower Oolites), 580.
Edgehill (Marlstone), 826.
Cotteswold Hills (Oolites): Broadway Hill, 1,086; Leckhampton Hill, 970; Cleeve Cloud, 1,134; Bredon Hill, 979.
Yorkshire Wolds (Chalk), Wilton Beacon, 805.
Lincolnshire Wolds (Chalk).
East Anglian Hills (Chalk), Gog Magog, 302.
Chiltern Hills (Chalk), 820.
Marlborough Downs (Chalk), Upcot Beacon, 887.
Hampshire Downs (Chalk), Inkpen Beacon, 972.
Wiltshire Downs: Long Knoll, Maiden Bradley (Chalk), 948; Alfred's Tower (Upper Greensand), 800.
Blackdown and Haldon Hills (Upper Greensand), 600 to 850.
Dorsetshire Hills (Upper Greensand): Pillesdon Pen, 934; Lewesdon Pen, 927.
Wealden Heights: Crowborough Beacon (Hastings Beds), 803; Leith Hill (Lower Greensand), 967; Hind Head (Lower Greensand), 894.
North Downs (Chalk), Limpsfield, 876.
South Downs (Chalk), Ditchling Beacon, 814.

VALES.

In the *Palæozoic rocks* are the Vales of Teifi and Towey in South Wales (Cambrian), and the Vales of Llanrwst (Silurian), and Llangollen (Silurian and Carboniferous), in North Wales.

In the *Poikilitic strata* are the Vales of Exeter and Taunton (Taunton Dean), the Vale of Wrington, Vale of Berkeley, Vale of Clwyd (Denbighshire), the Vale of York, and Vale of Eden.

In the *Lias*, the Vale of Ilchester (partly Alluvium), Vale of Gloucester, Vale of Moreton, Vale of Evesham, Vale of Red Horse (Warwickshire), Vale of Belvoir, and Vale of Catmos (Oakham).

In the *Oxford Clay* are the Vale of Blackmore (Dorset), and the Vale of Bedford.

In the *Kimeridge Clay* are the Vale of Wardour (Dorsetshire), and Vale of Pickering (Yorkshire), partly on the Neocomian.

In the *Wealden district* is the old Vale of Holmesdale or Valley of the Weald: this area is sometimes termed a plain.

In the *Gault* and *Upper Greensand* are the Vale of White Horse (near Shrivenham and Wantage), Vale of Aylesbury (the most fertile tract in England), and the Vale of Pusey or Pewsey in Wiltshire.

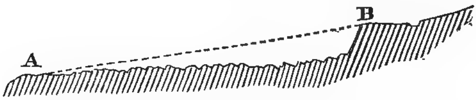
Plains.

The indefinite areas termed Plains are chiefly Secondary and more recent. Thus, the Cumbrian Plain (including Vale of Eden), the Cheshire Plain, the Plain of York, the North and South Clays (between Gainsborough and Nottingham), and the Severn Valley are chiefly *Poikilitic*. The central plain of England is chiefly Liassic, with much Drift. Salisbury Plain is Chalk. The Eastern Plain is chiefly Chalk covered with Drift. The Lower Thames Valley chiefly Tertiary and Alluvium; the Fenland, Somersetshire Levels, Holderness, &c., chiefly Alluvium.

We may now turn to the question of the origin of the principal features. Many years ago Prof. Ramsay noticed that in constructing a section across Wales, through the more hilly or mountainous regions, a line might be drawn from one end to the other which would touch, or nearly touch, all the more important elevations. The whole of the rocks of Palæozoic age which form these regions are much disturbed or contorted, being bent into folds, and at the same time irrespective of the shape of the hills. He demonstrated that while filling up the valleys in imagination, there yet remained a vast amount of material that had been removed above the line which touched the tops of the hills. This line indicated to him a Plain of Marine Denudation. Before the tract was elevated to its present position, and probably

during a period of gradual submergence, the sea worked away, as it does now on many parts of our coasts, such as at Watchet or near the mouth of the Thames at Southend, shaving off the inequalities, and forming a plain of rock (whether stone or clay) barely covered at low tide. The plain formed in Wales was of course a very extensive one, and then, after the area was elevated, atmospheric denudation came into play.

FIG. 24.—*Diagram illustrating the encroachment of the sea near Watchet.*[1]



A.—Old surface showing stumps of trees. B.—Present cliff-line. The dotted line A B shows the minimum quantity of rock removed.

Thus in Wales, the higher land, as it now exists, is only the relics of an average gentle slope, represented by a straight line drawn from the inland heights towards the sea.

Rents, joints, and fissures in the rocks no doubt gave a first direction to many of the valleys, which have been enlarged by rain, and streams, and rivers, and even by glaciers. So that really the main features of Wales, as we now see them, are due chiefly to fresh-water denudation, although there is every reason to suppose that the sea exercised some modifying influence on the land during the long course of ages and the many changes it has seen since the later Palæozoic times.

Escarpments.—We may now turn to the escarpments of the Oolites and Chalk, which are the next grand features we have to consider.

The term Escarpment is generally applied to a ridge of elevated country formed by the outcrop of certain strata, or

[1] This woodcut is borrowed from Mackintosh's *Scenery of England and Wales*, p. 35.

to use the words of Mr. Whitaker, 'It may be defined as the bounding ridge of a formation or bed, that is to say the ridge along which a formation or bed is cut off, and beyond which it does not extend, except in the form of outliers; it follows the line of strike.' The Cotteswold Hills are the 'escarpment' of the Oolites, and they really consist of several minor escarpments (see fig. 15, p. 176); the Polden Hills, in Somersetshire, are the 'escarpment' of the Lower Lias and Penarth Beds; the North and South Downs are escarpments of the Chalk. In the Carboniferous rocks, the scars and terraces of the Yorkshire dales may be cited.

The origin of Escarpments has been a fertile source of discussion, but the subject can only here be treated of in a large way, and, firstly, the former extension of the strata must be alluded to.

Prof. Ramsay believes that the Lias and Oolites entirely surrounded the old land of Wales, passing westwards through what is now the Bristol Channel on the south, and the broad tract of New Red formations that lie between Wales and the Lancashire hills, now partly occupied by the estuaries of the Dee and Mersey. He considers too that the Chalk in its day also spread far to the west, covering unconformably the half-denuded Oolites, till in its early beginning it abutted upon the ancient land formed of the Palæozoic strata of Wales, and by-and-by, as that land sank in the sea, buried it perhaps in places altogether.

Before the Chalk and other Cretaceous strata were deposited in the West of England, the Oolites and Lias had been disturbed and denuded, so that the former beds overlap the successive members of the latter. The older strata seem to have been planed off, and probably by the sea, before the Chalk and Greensand were deposited. The Chalk escarpment was therefore no doubt the first *escarpment* formed. But this was only formed after the area had become for a

second time a plain of marine denudation, which denudation probably exposed the Greensand in places in Devonshire. After this great denudation then the escarpments of Chalk and Greensand, and subsequently those of the lower Secondary strata were formed.

The Chalk was certainly much denuded in Eocene times, for the pebble-beds of this age are largely, sometimes entirely, made up of flints. But there is every reason to believe that a large amount of the Chalk has been removed subsequently, and that then the escarpments of it were for the most part formed. There seems to be no doubt that a great deal of subaërial denudation was effected in Miocene times, when we know that our country formed a land area. The plant-remains of these times found at Bovey Tracey bespeak a sub-tropical climate, which we may reasonably believe to have been attended by rainy seasons such as we do not experience now, and these rains would act more powerfully in accelerating subaërial denudation.

We now find the Chalk and the Oolites forming long lines of hilly ground or escarpments, as they are termed, with here and there an outlying hill. The rivers, too, often cut directly through them in the most remarkable manner. The rocks forming these escarpments dip on the whole gently to the south-east, a feature produced no doubt during elevation of the strata above the sea-level.[1]

The history of the origin of our rivers and their valleys is a large subject, and one which opens up many difficult questions in physical geology. The subject was first clearly brought into notice by the late Mr. Jukes, and Prof. Ramsay, who has paid great attention to it, has treated of the origin of several of our most important rivers.

[1] On this subject see Topley, on the Correspondence between some Areas of Apparent Upheaval and the Thickening of Subjacent Beds. *Quart. Journ. Geol. Soc.*, vol. xxx. p. 186.

It seems clear that many of them originated in very early times, although their courses have been modified, and even the direction of their flow changed, in subsequent periods.

Their researches have taught us that the reason why so many rivers cut through escarpments is that they originated before the escarpments were formed, and cut their way down through the strata which afterwards by atmospheric denudation receded. The fact that escarpments have thus receded is plain, although rather difficult to account for. Their formation is often attributed to marine action, but there are so few facts to corroborate this notion, that the opinion now generally held is that they are for the most part due to atmospheric denudation. The Chalk escarpment, as Prof. Ramsay observes, being more easily wasted than that of the Oolites, its recession eastwards has been more rapid.

It is true that the formation or recession of escarpments by subaërial agency does not, on first thought, seem altogether satisfactory, but Prof. Ramsay, Mr. Whitaker, Col. Greenwood, Dr. Foster, Mr. Topley, and others, have brought forward abundant evidence to show that the sea has played no prominent part in their formation, and that they are due chiefly to the slow and silent action of rain, and tiny streams and rivers. The fact that the rivers, which have cut through escarpments, are fed by streams that run parallel to the escarpments, is important. Prof. Green has stated that in the Carboniferous rocks of the north of England, where the dip of some hard rock was in a certain direction, and it was overlaid by softer strata, it was constantly the case that a brook ran along the line of junction, undermining the softer beds, bringing them down into the stream, and then removing them. It was in this manner that escarpments receded. The agency of small landslips is thus very important.

In order to arrive at true conclusions concerning the origin of escarpments we must bear in mind the following

important facts. Escarpments are formed almost invariably of porous rocks such as limestone or sandstone, while at their base is exposed a clayey or marly series of strata impervious to water. These again often rest on hard rocks forming another escarpment, the beds of which dip away from the plain beneath.

The beds may have been reduced to a tolerably even level by marine denudation after being subjected to the disturbances and undulations produced during their elevation, and these very disturbances may have partly affected the character of the plain of marine denudation, which does not necessarily mean a dead-level, and gentle curves or slight ridges of the harder rocks may have been left as a guide to the subsequent subaërial denudation.

Sea-waves (says the Rev. Osmond Fisher) cannot excavate long narrow inlets in homogeneous beds (such as Chalk), nor in horizontal beds, such as gravel and clay; for the effect of sea-waves is to form long and approximately straight lines of cliff. Any curvature seen in such a line of cliff will be found to be due to some disturbing cause, as a variation in the resisting power of the strata, or the set of a current, or exposure of some parts to a greater force of wind, in which cases a bay will be formed, but not a long and winding creek.

Jukes has remarked that *Calcareous* rock is acted upon both by mechanical erosion and chemical solution—*Siliceous* rock only by mechanical erosion. Both rocks are denuded equally by the sea. Therefore when one area of calcareous rock is denuded more largely than a neighbouring one of siliceous strata, we must attribute the denudation to Atmospheric agency.

Mr. Whitaker has made the following Comparative Table of the distinctive features of Escarpments and Cliffs[1]:—

[1] He refers, from personal experience, chiefly to our Cretaceous and Tertiary formations.

Escarpments.	*Cliffs.*
(*a*) Run along the strike, or in other words, keep to one formation throughout.	(*a*) Rarely run along the strike, but at all angles to it, and cut through many formations in succession.
(*b*) Tops more or less even, and often nearly flat.	(*b*) Tops mostly very uneven.
(*c*) Form the highest ground of a country, overlooking other parts.	(*c*) Rarely through the highest ground of a country, but mostly backed by higher ground.
(*d*) Very rarely have the sea at their foot, but often springs and watercourses.	(*d*) Sea at their foot.
(*e*) Often run in more or less winding lines, though in general direction following the strike.	(*e*) Run nearly straight, or in curves of very large radius, when through homogeneous rock, and when not broken through by valleys.
(*f*) No beach at their foot.	(*f*) Often a beach at their foot.
(*g*) Are now being destroyed by the sea in places where the sea touches them.	(*g*) Are now being made by the sea (aided by atmospheric actions).
(*h*) Bases rise towards the watershed, and have nothing to do with the sea-level.	(*h*) Bases at the sea-level, or very near it.
(*i*) Those of successive formations run in more or less parallel lines for long distances, with plains, vales, or valleys, between them.	(*i*) No such parallel arrangement known, long fringes of land divided by belts of sea not being common, except in such cases as Coral Islands, where the features have been formed by growth, not by decay.
(*j*) Valleys and combes are not abruptly cut off by them.	(*j*) Small valleys and combes are often abruptly cut off by them.
(*k*) Beyond them the ground soon rises above their bases.	(*k*) Beyond them the ground falls below their bases (beneath the sea).
(*l*) The waterslopes of valleys that breach them fall inwards from them (rising outwards of course).	(*l*) The waterslopes of valleys that breach them rise inwards from them.

Escarpments.	*Cliffs.*
(*m*) Rivers and valleys have their heads at or near them. Water flows away from them at last.	(*m*) Rivers and valleys end at them. Water flows to them in the end.

The denudation of the Wealden district has been a fertile source of discussion, and has an important bearing on the origin of escarpments. It will be unnecessary here to refer to the many papers that have been written upon the subject, and we may be content with giving Prof. Ramsay's views.[1] By drawing a section across the district from the North to the South Downs, and connecting the Chalk and other strata on either side, a dome-shaped or anticlinal structure will be formed. (See fig. 17, p. 211.) This dome was probably removed by the sea which formed a sort of plain of marine denudation, leaving at the same time a low central watershed from which in old times the rivers probably flowed, and thus formed their channels through the Chalk, whose origin seems inexplicable on any other supposition. In due time rain and river-action diversified the scenery, the Chalk escarpments receding, the soft Gault forming a hollow, the Lower Greensand standing out in bold hills, overlooking the plain of Weald Clay, and the harder rocks of the Hastings Sand series again rising to a high elevation.

The Tertiary deposits form no very regular features, and this is in great measure owing to their soft nature, the absence of hard beds in them, and the absence of any hard strata above them of the nature to form an escarpment. The valleys that have been excavated in them are numerous, and some of the higher hills, like those of Harrow and Langdon Hill, command extensive views, while the scenery at Highgate and Hampstead, at Brentwood and near Rayleigh, is

[1] The same views were worked out in great detail by Messrs. Foster and Topley. See *Quart. Journ. Geol. Soc.* vol. xxi. p. 443.

very picturesque. Most of the valleys have been probably formed by river-action, taking their direction, perhaps, from slight dislocations or undulations in the strata.

The Glacial deposits and superficial gravels do not affect the marked features of our country, but their distribution gives us some clue to the date when those features assumed their present form. These drift deposits rest indifferently upon the Tertiary and older strata, and they rest irregularly on the surface, clearly showing that the main features we now see were Pre-Glacial.

The influence of glaciers, which are well known to have existed on the high grounds of Wales and in the Lake District, has been spoken of, and some of the valleys have been considerably modified, if not to a great extent formed, by them. The dales of Yorkshire, for instance, may have been partly fashioned by glacial as well as fluviatile action.

It will be easily understood why the Alluvium should form such scenery as it does—belts of low-lying meadow land bordering the rivers and streams—but why the rivers should have formed so much sediment along their courses is not at once easy to understand. It must be remembered, however, that in all times from the most remote to the present day changes of level continually take place, and such changes greatly affect denudation and deposition. A slight submergence would cause a river to flood its banks and deposit sediment, whereas elevation would tend to make it deepen its channel and so remove more material. A river, as is well known, is incessantly changing its course in however small a degree, and when we see broad flats of Alluvium bordering a small stream, it does not follow that the stream once entirely filled that broad channel, but that in the course of time it has occupied different positions in that valley.

The nature of the river valleys of course depends upon the nature of the rocks traversed by the river, bold cliffs

being commonly formed in hard rocks, but hardly ever in soft strata.

The alternation of hard and soft strata along a river course may lead to the formation of a lake, the softer strata being worn away and the harder forming barriers at either end. Lakes, indeed, may be due to various causes or a combination of causes. Some large lakes are relics of old sea-bottoms, others lie in the craters of extinct volcanos. Glaciers may plough out hollows, or deposit moraines which form barriers.[1] Faulting and disturbance of strata in some cases appear to have had considerable influence in the formation of lakes, and it is well to be cautious in studying the origin of lake-basins and to bear in mind the many and complicated causes to which they may be due.

The Broads of East Norfolk appear to be expansions of the rivers, but some of them are considerably deeper than the rivers, and in the opinion of Messrs. Wood and Harmer depression of the land during comparatively recent times caused the sea to fill valleys and so help to form the Broads.[2]

Waterfalls are sometimes produced by the passage of a stream or river along its channel, from hard rocks to soft, the latter being worn away, while the former beds stand out as ledges; they may also be formed where a stream runs out to sea over a cliff.[3]

Such phenomena, however, must be considered as minor features in our scenery, and they have been produced by many local causes.

In limestone districts, as in Derbyshire and Somerset-

[1] Mr. J. Clifton Ward has demonstrated the Glacial origin of some of the rock-bound lake-basins of Cumberland and Westmoreland.

[2] The Meres of Norfolk are isolated ponds whose supply of water is derived almost directly from the rain-fall.

[3] The 'Chines' of the Isle of Wight, and the 'Bunnies' of Hampshire, are gullies which have been formed by the action of springs in making their way over the cliffs into the sea.

shire, the power of rain-water holding carbonic acid is very great in dissolving the rock and forming caverns. (See p. 347.)

It has been supposed that some of the dales and ravines may originally have been caverns. Be this as it may, the action is the same: these limestone combes and dales have been formed by running water, assisted no doubt by the mechanical action of frost and the chemical action of carbonated water.

The course of rivers underground through swallow-holes has been before alluded to, and the material they would thus remove cannot be inconsiderable. (See p. 344.)

Cheddar Cliffs.[1]—The origin of the narrow winding gorge in the Carboniferous Limestone at Cheddar has been a source of some discussion. The popular notion of a rent or violent disruption is at once disproved by a glance at the dip of the strata, which is regular on both sides of the chasm. The idea that the sea was the great agent is also an assumption unwarranted by the nature of the gorge itself.

That the Cliffs originated in a fissure or crack in the Carboniferous Limestone may be safely assumed. There are plenty of these in the Mendip Hills. The dips in the Limestone strata, which were very carefully taken by Mr. J. H. Blake, show a trifling variation on either side of the gorge, varying on the one side from 19° to 24°, and on the other from 15° to 23°; all are in the same direction of south, or a few degrees east of south.

One fact that will immediately strike an observer, is that nearly all the material removed has been taken from one, the northern side of the ravine. (See frontispiece.) This is important, for it demonstrates that the dip of the beds exercised a great influence upon the formation of the cliffs.

[1] The highest point is said to be 420 feet.

The fissure, which in the first instance was formed, would be a line of drainage, and the water running through it, partly underground, not only by mechanical action, but also by chemical agency, would dissolve and wear away the limestone. Frost, too, is an active agent in disintegrating fragments from the sides of the ravine; and on the northern side its influence being far greater, large masses of the limestone would be dislodged and fall by mere gravitation into the gorge. The formation of the Cheddar Cliffs may have commenced before the lower Secondary strata were denuded in the vale of Wrington, so that the stream which helped to form them would have run over an old plain of deposition, just as the Avon did when it commenced to form the gorge at Clifton.

Weathering of Limestone.—The surface of the Carboniferous Limestone is frequently weathered into curious hollows and fantastic shapes, used for Rustic work. These features are met with in exposed situations, and are often found on the removal of the turf.

By far the larger number of holes and irregular cavities in limestone are undoubtedly due to atmospheric wear and tear, but owing to the occasional presence of the common land-snails in them some have been attributed to the boring power of these Mollusca. Mr. John Rofe,[1] discussing the subject, considers that the odontophore of snails, which is a cartilaginous strap bearing a long series of teeth, is capable of producing small cavities in limestone rocks. More evidence is needed on this point, although, as snails would need calcareous matter for their shells, they may have some object in rasping away at limestone rocks.

The action of the weather on the Carboniferous Limestone is often conspicuous. In an old quarry west of the Ebber rocks

[1] Long ago Dr. Buckland, and subsequently M. Bouchard-Chantereaux, advocated the boring powers of snails.

I noticed some deep furrows on a face of the rock, which was dipping at an angle of 45°. One channel varying in width from 3 inches to 1 foot, was in places 6 inches in depth; another, from 2 to 4 inches in width, was from $1\frac{1}{2}$ inches to 4 inches in depth.

Prof. Phillips, alluding to the action of the weather, by means of rain, frost, and carbonic acid, on the Oolitic rocks, says: 'Thus are the beds broken up into small fragments, the natural joints widened, and their sides penetrated; the surfaces of the rocks pitted and undulated, so as to produce in exposed situations very fantastic hollows, branching ridges, and crests, called Rustic work, which often shelter land-snails, and sometimes suggest the idea of these animals having made the holes into which they retire.'

In some districts inland, and also near the coast, but above the present level of the sea, holes are found in limestone rocks which have been attributed to Pholas. Many are doubtless bored by this mollusc, which can pierce almost any rock; but their burrows are of a pear-shape or pyriform character, and can hardly be mistaken, although there is no reason to doubt that the atmosphere could mimic these forms, so varied are the shapes it can fashion.[1]

The formation of Caverns has been previously treated of: those formed inland by subaërial agents in *calcareous* rocks, are very distinct from the caves fashioned *in any rock* by the sea along the coast. Many of the latter are formed along lines of bedding or joints. (See fig. 16, p. 207.)

The Chalk is worn away into pipes and hollows,[2] frequently causing subsidences of the ground (see fig. 21, p. 287);

[1] Holes considered to be bored by *Pholas* have been noticed in the Devonian Limestone near Torquay, at a height of 200 feet above sea-level; and in the Carboniferous Limestone of Little and Great Ormes Heads, at heights up to 570 feet above sea-level.

[2] Called 'Earth-pots' in Norfolk, and sometimes 'Sand-galls.'

and in the salt districts the dissolving action of rain-water sometimes forms extensive settlements or subsidences of the surface. The flints in the 'Clay-with-flints' on the Chalk tracts are considered to be due to the atmospheric dissolution of the Chalk. (See p. 361.)

Tors, Logan-stones, &c.—There are some other minor features which deserve a passing notice. The occurrence of large masses of loose rock may be due to the jointage of beds and their being weathered out *in situ*; other rocks may jut out naturally and be weathered into fantastic shapes, and not only pluvial action may influence them, but in some cases wind carrying sand has exerted great power in furrowing or in polishing rocks.

Most of the Palæozoic rocks, and the igneous rocks and granites, jut out here and there on the hill-sides, and form often a rough barren country, when they yield little or no soil.

Large blocks of stone may also have been brought from a distance by a glacier or iceberg and so deposited.[1]

Granite (to quote Sir Charles Lyell) often preserves a very uniform character throughout a wide range of territory, forming hills of a peculiar rounded form, usually clad with a scanty vegetation. The surface of the rock is for the most part in a crumbling state, and the hills are often surmounted by piles of stones like the remains of a stratified mass, and sometimes like heaps of boulders, for which they have been mistaken. The exterior of these stones, originally quadrangular, acquires a rounded form by the action of air and water, for the edges and angles waste away more rapidly than the sides.

Thus spheroidal blocks are weathered out *in situ*, and often form Logans or Rocking Stones.

[1] Large boulders which have been transported by ice, and which by its melting have been left in isolated situations, are called *Blocs perchés*.

The Nutcracker, a Logan in Lustleigh Cleave, in Devonshire, is situated on the side of the hill, and according to Mr. G. W. Ormerod, has rolled down from above.

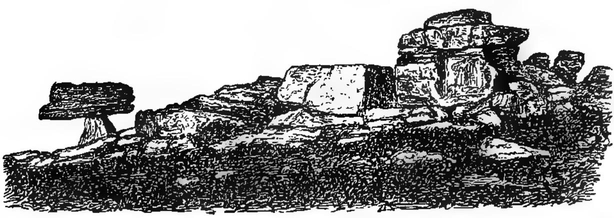
The best known Logan is that situated in Cornwall, near Castle Treryn, St. Leven. It rocks only in one direction; and a quantity of loose quartzose gravel may be found near the points of contact, marking the progress of disintegration. In size it is about 17 feet in length and $32\frac{1}{2}$ in circumference about the middle part; the weight appears to be about 65 tons.

FIG. 25.—*The Cheesewring.*[1]

The various Tors of Cornwall and Dartmoor are similar exhibitions of the weathering of Granite.

The Cheesewring occupies the highest ridge of a hill to the north of Liskeard. This granitic pile is about 15 feet in height. (See fig. 25.)

FIG. 26.—*Part of Rippon Tors, Dartmoor.*[1]



Helmen Tor, on Dartmoor, is a rugged hill composed of blocks of granite, several of which rock with ease.

Rippon Tors are familiar to most tourists, as is also Hey Tor near Bovey Tracey, which is very conspicuous in the country around Torquay and Newton Abbot. (See fig. 26.)

[1] These woodcuts are borrowed from Mackintosh's *Scenery of England and Wales*, pp. 179, 180.

Atmospheric action, as pointed out by Mr. Ormerod, has produced the curious rock-basins formed on many of the Tors and isolated rocks of Dartmoor.

Prof. Phillips has remarked that 'Frequently in looking at buildings composed of porous materials, like the Portland stone or a grit freestone, we observe the parts which are overhung by a ledge, and thus kept in a state of continual shade and dampness, to be more rapidly consumed than the projections; but the parts which hasten soonest to decay are those near the ground. The same rules are exemplified in many remarkable rocks, as, for instance, in the quartzose conglomerates of the Old Red Sandstone of Monmouthshire and the Millstone grit of Brimham Crags in Yorkshire. The "Buckstone," near Monmouth, is a huge rock inversely conical, expanded above into a large area, but contracted below by continual waste to a narrow base of attachment. This process a little further continued might convert the Buckstone, as probably some of the stones of Brimham have been converted, into a "rocking-stone."' (See fig. 9, p. 90.)

Some of the modern results of denudation, as, for instance, alluvial deposits, landslips, &c., have been alluded to in previous chapters.

The effects of modern denudation are indeed of the highest interest to the geologist, and the estimated loss of land by subaërial waste and by marine denudation has formed the subject of much research. We want more data as regards denudation in our own country, but we must not overlook the great influence exerted by man in the protection of our coast-line in many places; nor the fact that in extending systems of drainage, and in the cutting down of forests, the rain-fall has to some extent been locally modified.[1]

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[1] Among the old forests of England on the *Palæozoic strata* were Charnwood Forest, the Forests of Dean, Exmoor, Dartmoor, and the

NOTES ON FEATURES OBSERVABLE ON THE MAIN LINES OF RAILWAY.

Our different lines of Railway have largely aided the progress of Geology, partly because they have opened up a ready means of communication to all parts of the country, but mainly because they have furnished some of the most important and instructive geological sections; yet while it would be impossible to attempt an enumeration of them, it may be interesting to point out some of the leading features observable on the great lines of railway.

Thus, in travelling from London along the main lines with the aid of a geological map, the character of the scenery may be studied with advantage in connection with the geological structure.

Great Eastern Railway.—Travelling by way of Colchester on the Great Eastern line we pass by the Thames Valley deposits—brickearth and gravel—near Stratford and Ilford, famous for their mammalian remains, and beyond Romford we get upon the bare London Clay, capped at Brentwood, in the deep cutting, by the Lower Bagshot beds. From this station to Ipswich we pass over the London Clay, covered here

Mendip Forest; on the *Poikilitic strata,* Delamere Forest (around Northwich and Chester), the Forest of Arden (Warwickshire), Needwood Forest (Staffordshire), Sherwood Forest (Nottinghamshire), North Petherton Forest (around Bridgewater); on the *Liassic strata,* Neroche Forest (including that of Ashill, to the west of Ilminster); on the *Oolitic strata,* Braydon Forest (west of Cricklade), Wychwood Forest (around Chipping Norton, Burford, and Whittlebury), Selwood Forest (between Frome and Wincanton), and Gillingham Forest (Dorset); on the *Wealden strata,* St. Leonard's and Tilgate Forests (near Horsham and East Grinstead); on the *Gault* and *Greensand,* Woolmer Forest (east of Selborne), Holt Forest (east of Alton); on the *Tertiaries,* the New Forest (Hampshire), Savernake Forest (Wilts), Windsor Forest (Berkshire), and Epping and Hainault Forests (Essex).

and there by Drift Gravel and Boulder Clay. Thence we cross over the Chalk, similarly capped by Drift, until we reach Norwich.

Proceeding from London by Cambridge we travel for some distance along the valley of the Lea, filled with Alluvial deposits, and bounded by low Tertiary hills capped with Drift, and we reach the Chalk near Bishop's Stortford. Thence in journeying to Norwich we pass over the Chalk, the lowest beds of which are seen at Cambridge, and between Ely and Brandon over the Alluvium; beyond which we cross the Chalk with Drift-beds which almost entirely cover the higher grounds, while in the valleys occur old Alluvial deposits which have yielded, as near Thetford, some of the earliest types of flint-implements formed by man.

Great Northern Railway.—On the Great Northern line we pass through tunnels and cuttings of London Clay as far as Hatfield, the bordering hills being capped by Drift Gravel and Boulder Clay as at Finchley and Barnet. Beyond Hatfield we pass over the Chalk with much gravel, chiefly that called Middle Glacial, and between Hitchin and Potton we cross the Lower Cretaceous beds; thence through Huntingdon and Peterborough to Stamford, we traverse a low-lying tract of country formed of Oxford Clay and Alluvium. Beyond this, and as far as Grantham, we cross the Lower Oolites, which near that town are well displayed in the cuttings in the Lincolnshire limestone, as are also the Boulder drifts (see p. 307). Passing over the Lias we reach Newark, situated near the junction of Lias, Rhætic Beds, and Red Marl. The Marls here yield much gypsum, which is worked for plaster of Paris. Thence we continue in the vales formed of Triassic and Permian strata, with some alluvium, by York, Northallerton, and Darlington. Through Durham, Newcastle, and Morpeth, we traverse the Coal-measures, and beyond these towns the line passes over the Lower Carboniferous

series with the coal-bearing representatives of the Mountain Limestone near Berwick-on-Tweed.

Midland Railway.—Starting from St. Pancras, we travel over the London Clay through Hendon, and Boreham Wood, until we cross the outcrop of the Reading Beds and reach the Chalk at Radlett station. Here a large pit by the railway shows the London Clay and Reading Beds capped by Drift Gravel (Middle Glacial); and in the park adjoining the Hertfordshire puddingstone was, at one time, very well shown in a pit. Proceeding towards St. Albans, we cross the Chalk, almost entirely obscured by deposits of Gravel and Brickearth (Middle Glacial), and thus we continue until beyond Luton, we traverse the Gault, and near Ampthill the Lower Greensand. Further on we come upon the Oxford Clay, and soon reach Bedford, which is situated on the borders of this Clay and the Lower Oolites. The gravels in the valley of the Ouse have yielded remains of *Hippopotamus*, etc., and some flint-implements, through the labours of Mr. J. Wyatt. Near Wellingborough we enter a valley which exposes the Lias, while above it come the Northampton Sands, now so largely worked for iron-ore. From Market Harborough to Leicester we cross the Lias, much obscured by Drift, but the lower beds, worked for cement-stones, are well exposed at Barrow-on-Soar, where the junction with the Rhætic beds may also be seen. At Mount Sorrel station we pass in view of the slaty and granitic hills of Charnwood Forest (to the west), and proceed across the Red Marl by Trent to Derby. Thence skirting the south-western corner of the Derbyshire Coal-field, we enter the Dale country at Matlock, passing for the most part through grand scenery in the Carboniferous Limestone from Bakewell by Monsal and Miller's Dale to Buxton. Then we proceed through the southern extremity of the Lancashire Coal-field (sometimes called the Cheshire Coal-field) by Stockport to Manchester.

London and North-Western Railway.—By the London and North-Western line we pass through the London Clay at the Primrose-hill tunnel, and thence across a thinly populated tract of country formed of the same deposit until we reach Watford, where the Reading Beds and Chalk are seen.

Several fine exposures of Chalk are then passed through in the cuttings, and near Ivinghoe the Upper Greensand and Gault are reached. At Leighton Buzzard we proceed over the Lower Greensand, and thence through the Oolitic country of Fenny and Stony Stratford, coming on to the Lias here and there in the deeper valleys, and crossing its broad outcrop near Daventry and Rugby.

Rugby is situated near the outcrop of the Rhætic or Penarth Beds, beyond which we traverse the marls and sandstones of the Trias, covered in places with much Drift gravel. Between Nuneaton and Tamworth we skirt and finally cross over a portion of the Warwickshire Coal-field, beyond which, by Lichfield, Stafford, and Crewe, we chiefly pass over Triassic beds with Drift gravels. Near Crewe the Upper Triassic beds yield the rock salt and brine springs. Beyond Crewe we continue over the Triassic beds by Warrington, cross the South Lancashire Coal-field near Wigan, and traverse the Triassic beds again through Preston on the borders of Alluvial flats.

At Lancaster the Coal-measure rocks are again reached, and further north we enter upon the Carboniferous Limestone as far as Kirkby Kendal. Beyond this we pass through the Silurian and Cambrian district, with traces of Old Red Sandstone, and more Carboniferous Limestone between Shap and Penrith. Here we enter upon the Permian rocks of the Vale of Eden, which, near Carlisle, are capped by Red Marls, Rhætic beds, and Lias. (See p. 122.)

If after reaching Rugby we proceed by Coventry to Birmingham, we cross different members of the Trias and Permian, and then traverse the 'Black Country' of the South

Staffordshire Coal-field to Wolverhampton. Thence we skirt the borders of the Silurian rocks of Wenlock and the Cambrian of the Longmynd at Wellington and Shrewsbury, and continue partly on the Triassic and Permian rocks and partly on the Coal-measures by Wrexham to Chester, and thence by the sea-shore round the Palæozoic rocks of North Wales to Bangor, and so on to Holyhead.

Great Western Railway.—Along the Great Western Railway for some distance, as far as and beyond Slough, we traverse the gravels and brickearth of the Thames Valley. At Maidenhead we reach the Chalk, and continue upon it as far as Reading and Moulsford, with the escarpment of lower Tertiary beds to the south. Beyond Moulsford we cross the Upper Greensand on to the Gault; Didcot being situated near the junction of the two. Thence, as far as Chippenham, the line passes for the greater part over low-lying clayey tracts of Gault, Kimeridge, and Oxford Clays. Thence we enter upon the Lower Oolitic country forming the southern extremity of the Cotteswold Hills, which rocks form such fine bold scenery in the valleys west of Chippenham and around Bath. The large quarries of Corsham and Box, and the long tunnel between the two, are situated in the Great Oolite.

At Saltford the Lower Lias and White Lias (the upper portion of the Penarth or Rhætic beds) are exposed; near Keynsham there are cuttings of Lias; and between this and Bristol most of the cuttings and tunnels are excavated in the Pennant Grit or Middle Coal-measures of the Bristol coal-field.

Leaving Bristol we traverse the little coal-field of Nailsea, and then proceed along the Alluvial flats that border the estuary of the Severn with little relief as far as Bridgewater. The cutting at Uphill, however, where the western extremity of the Mendip Hills is traversed, shows a fine cutting of

Lower Lias, Penarth Beds, and Red Marl, faulted against the Mountain Limestone. (See fig. 27.) At Puriton cutting too a fine section of Penarth Beds and Lower Lias is exposed.

Beyond Bridgewater we traverse the vale of Taunton, formed of Triassic marls, sandstones, and conglomerates; bordered on the west by the Devonian and Carboniferous rocks, and on the east or south-east by the Greensand heights of Blackdown, upon a spur of which the Wellington Monument is situated. Beyond Exeter, at Dawlish and Teignmouth, the railway runs at the foot of the fine cliffs of Triassic sandstone, breccia, and conglomerate, and thence borders the estuary of the Teign to Newton Abbot. Here in the higher part of the valley are the Miocene clays so largely worked for the potteries, and the interesting lignite-beds of Bovey Tracey. Beyond Newton we come to the Devonian limestones, and thence by Totnes as far as Plymouth the line passes for the most part over the Devonian slaty rocks, the granitic range of Dartmoor being skirted on its southern margin. At Plymouth the Devonian limestones are well developed, and thence into Cornwall we pass over a country chiefly made up of Devonian slates or 'killas,' and granite, with a cutting in the serpentine at Menheniot.

London and South-Western Railway.—On the London and South-Western Railway we pass over the Alluvial beds and Lower Eocene strata to near Walton-on-Thames, and then enter upon the sandy and heathy country formed by the Bagshot Beds, which extends beyond Farnborough. At Basingstoke we come upon the Chalk and traverse it as far as Salisbury and for some distance beyond, when we enter the Vale of Wardour, formed in the Kimeridge Clay and Portland beds of Tisbury, and bounded by the escarpments of Upper Greensand and Chalk. Leaving the flat country of Kimeridge Clay near Gillingham, we cross the outcrop of the Coral Rag and enter upon another tract of flat country

formed in the Oxford Clay, which reaches to Templecombe. Beyond this we enter upon the country formed of the Lower Oolites, coming east of Sherborne, however, into the Alluvial flats of the valley of the Yeo. At Yeovil Junction are fine sections of the Sands below the Inferior Oolite, and both here and at Crewkerne sections of the Inferior Oolite are also exposed. Between Crewkerne and Axminster we cross the Liassic beds capped here and there on either side of the line by conspicuous outlying masses of Chalk and Upper Greensand.

Axminster is situated near the junction of the Penarth Beds and the Red Marls of the Upper Trias. Proceeding towards Honiton we pass over these latter beds capped by Greensand, and in the cutting at the eastern end of the long tunnel are traces of Gault at the base of the Greensand. At Honiton the escarpments of the Upper Greensand are very bold; thence we pass over various members of the Trias, as far as Exeter. Exeter is situated partly on the Culm Measures, and thence in travelling to Barnstaple, with the exception of crossing a tongue of the Triassic beds by Crediton, we pass through an undulating country formed of these Upper Carboniferous rocks.

The lines of railway running south of London all cross the Lower Eocene strata and Chalk, and thence many of them traverse the picturesque district of the Weald.

Chapter XIV.

GEOLOGY IN THE FIELD—ITS ECONOMIC AND SCIENTIFIC BEARINGS—(conclusion).

In the former pages I have indicated the leading characters by which our formations and their many subdivisions may be identified, and I have endeavoured to point out in a general way the principal causes which have contributed to the formation of our scenery.

Before resigning my task I have thought it well to note down for the use of the student who may take this book as a guide in his field-researches, some of the principal petrological or structural features that affect our rocks.[1]

The 'lie,' or general inclination of the strata is called the *Dip*. (See fig. 14, p. 145.)

While observing the general direction or dip of the beds, care must be taken to discriminate between this and '*Slaty cleavage*,' which often cuts up the Palæozoic strata at all

[1] Equipped with note-book, hammer, compass, clinometer, pocket-lens, pen-knife, and protractor with scale; and with perhaps also a bag, and small bottle of hydrochloric acid, the geological student would be prepared for work of all kinds. The shape of the hammer will, however, depend greatly on the nature of the rocks examined. The clinometer will be useful for registering the 'dip' or angle of inclination of the strata. The pocket-lens will be of service in determining whether the rock be crystalline or composed of a mechanical aggregate of rounded or angular fragments. The pen-knife will, by its determination of hardness, indicate a very siliceous from a calcareous rock. Hydrochloric acid will detect the limestones and marls.

angles, and is a phenomenon produced by pressure subsequent to the consolidation of the beds. So difficult is this that the late Prof. Jukes has remarked you may sometimes 'toss up' which is cleavage and bedding and jointing.

Bedding is the term applied to marked lines of stratification which separate the rock into beds and probably indicate a pause in deposition. *Lamination*, which is most conspicuous in clays and shales, is applied to the splitting of rocks into thin films, which are no doubt the original layers of deposition. *Jointing* is probably produced by shrinkage. It occurs generally at right angles to the bedding. Joints are enlarged by the action of water and converted into fissures. (See fig. 16, p. 207.)

False-bedding or *Oblique lamination* is a feature produced in shallow water by currents and tidal action, whereby beds are heaped up in irregular layers without any approach to horizontality or continuity. (See fig. 13, p. 137.)

Foliation is a chemical or molecular arrangement of mineral matter in alternate layers of different composition. (See p. 366.)

Terminal curvature is applied to the local and superficial disturbance of shaly and slaty rocks whereby the beds (or their cleavage planes) are bent over and present an opposite direction in dip to the beds below. It is probably due to several causes; in some instances it is traceable to the action of the weather, and particularly of frosts, while in others the appearances may be caused by the roots of trees; again, many cases seem to require some more powerful disturbing cause and are suggestive of glacial action.[1] Care must be taken to distinguish it from any original disturbances which may have affected the beds. (See p. 317.)

[1] Mr. Mackintosh states that near Gupworthy in West Somerset, the bending back of the laminæ of slate is on so extensive a scale as to point to the long continued action of a great flow of continental ice, or to the grazing force of grounding icebergs.

Jukes has observed that in making observations on the dip of the beds in a great section of slates, even the most practised observers may be occasionally led astray. If the beds undulate while the dip of the cleavage is steady, and if the substance of the slate be very homogeneous, it may easily happen that the stratification is only well shown when it has a given relation to the cleavage; when, for instance, they coincide, or when they are at right angles to each other, or when they cross at some other angle, so that the particular mark of stratification which the kind of slate possesses shall be least obscured by the cleavage.

To determine the true dip when the beds are affected by 'cleavage,' lines of organic remains, and flaggy or gritty bands must be looked out for; sometimes this may be done by evidence of what Sedgwick called the 'stripe,' which consists of bands of different colour, whether grey, purple, or green, which run through the slaty rocks and indicate different layers of mineral matter.

In rare cases disturbances seem to have contorted the cleavage planes.

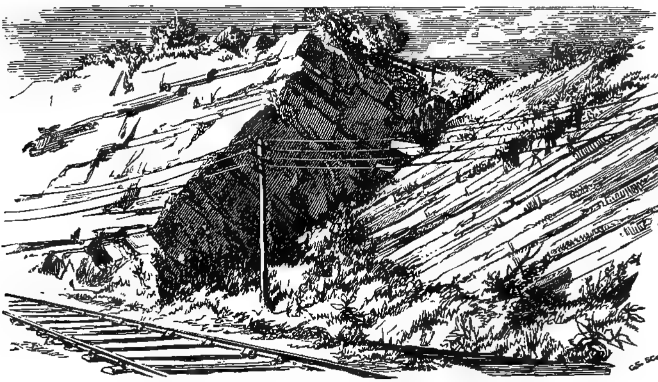
The Strike is the line of outcrop of beds along a level surface; it is the line of greatest upheaval. In England the Neozoic (Secondary and Tertiary) beds dip generally to the south-east, consequently the strike is north-east and south-west.

In tracing the boundary line of a formation belonging to a conformable series as the Carboniferous or Secondary strata, the dip is a constant guide. Where this takes a low angle of 3° or 4°, a very small irregularity in the ground, a gentle hollow, may cause the boundary to run a long way from the line of strike; whereas, with a high dip, the lower beds would run but a short distance even in a deep valley or ravine.

The edges of a formation, exposed by denudation, are called its *outcrop* or *basset*.

Faults are disturbances in the strata whereby older rocks are brought into abrupt contact with newer. They are fractures in the earth's crust attended by the upheaval of one side of the ground and the downthrow of the other; the amount of the shifting is called the throw, and the dip or direction underground is called its hade. This is generally in the direction of the downthrow. Care must be taken not to confound unconformabilities with faults, where a newer set of strata abut on a cliff of older rocks against which they

FIG. 27.—*Cutting near Uphill* (*Bristol and Exeter Railway*).



a. Lower Lias. b. Carboniferous Limestone.

[This woodcut should represent the cutting on the eastern side of the railway, but unfortunately the drawing was not reversed on the block.]

were deposited. This may, however, be proved by the sedimentary nature of the newer deposit. (See fig. 8, p. 84.)

Faults generally approach near to a straight line in the direction they take, although of course they are much modified in their superficial outline by the shape of the ground and the amount of the hade.

The material filling a fault, is sometimes called the 'clog'

or 'Fault rock;' this naturally varies according to the nature of the rocks affected, being either clay, rubble or breccia.

Reversed faults are so called when the beds dislocated over-lap one another, that is to say, supposing the hade of a fault to be in an easterly direction, then if the beds are upraised on the east, instead, as would usually be the case, of being thrown down on that side, this would be a reversed fault. Nevertheless it is not always easy or possible to determine in a small section if an apparently reversed fault is really so, for the reversed hade may be merely an irregularity in the hade of an ordinary fault. (See fig. 27.)

The walls of a fault are sometimes grooved or striated by the friction attending the disturbance which produced it: the walls are then '*slickensides*.' In limestones the groovings are often obscured by a stalactitic coating of carbonate of lime.

One of the largest and most important faults in England and Wales is the Pennine Fault, which commences in the south of Scotland, and runs southwards to near Brough in Westmoreland. On the eastern side Carboniferous rocks, Old Red Sandstone, and even Silurian strata are brought against the Permian rocks on the west, with a maximum throw estimated at from 6,000 to 7,000 feet. The fault continues by Kirkby Stephen to near Kirkby Lonsdale: this portion being considered the continuation of the Pennine fault by John Phillips, and the commencement of the Craven fault by Sedgwick.

The Craven fault then runs in a south-easterly direction from Kirkby Lonsdale.

The Tynedale fault, and the Symon fault in Coalbrookdale, are also very important ones.

The 'Ninety-fathom dyke,' in the Newcastle Coal-field, is so called because the same beds are 90 fathoms lower on the northern than on the southern side of the fault.

The Radstock slide-fault in the Somersetshire Coal district

is a curious example of beds faulted in a nearly horizontal position, for it has thrust the upper portion of the Radstock series over the lower half, back from the direction of the Mendips northward, for a distance from 50 to 350 yards.

Sometimes in the neighbourhood of a fault the beds exhibit an attenuation. In contrast to this attenuation are what are termed 'wants' in strata, which consist of interrupted (broken, not nodular) bands of hard rock in a clayey or shaly formation.

In the former case the facts might lead to the supposition that the disturbance took place before the beds were thoroughly consolidated, but the experiments made by Mr. L. C. Miall tend to show that most rocks are both elastic and plastic, when subjected to long continued pressures or strains of low intensity. The 'wants' on the other hand would indicate a more sudden strain, the hard bands indicating the tension by separation, whilst the clayey beds, as Mr. Jack has pointed out, do not lose their continuity.

Where one formation succeeds another, and extends over its margin, this is called *Overlap*, and is no doubt due to the sinking of the area of deposition. This is the case in the Mendip country, where the Lias overlaps the Penarth Beds. (See fig. 8, p. 84.) Where, however, one formation stretches over the outcrops of a series of strata, this is an unconformable overlap or unconformability: as where the Chalk and Greensand stretch across the outcrops of the Lower Secondary strata in Dorset and Devon.

Patches of a formation which have been separated from the main mass by denudation are called *Outliers*; and when a formation is exposed over a small area beneath a newer formation which encircles it, this exposure is called an *Inlier*. An inlier is generally produced by disturbance. Where a hill of some older rock is encircled by a tract of Alluvium, or a boss of rock is exposed in an area composed of much

newer strata, such hills and bosses are sometimes termed Islands.

The strata are sometimes disturbed and bent into folds; the basins or troughs of these undulations are called *synclinals*, the saddles or ridges *anticlinals*. (See fig. 8, p. 84, and fig. 21, p. 287.) When the strata are very rapidly and irregularly folded they are said to be *contorted*.

Sometimes the beds are actually folded over or *inverted*. On the northern side of the Mendip Hills the Coal-measures are so much disturbed and contorted that the same coal-seam has been penetrated three times in one shaft. The most interesting features in connection with these disturbances are the little patches of Carboniferous Limestone which at Luckington and Vobster occur in the midst of the Coal-district, and beneath which in places coal has been worked. The position of these masses seems to be due to a complicated system of inversion and faulting.

Prof. Phillips has pointed out that in the Abberley district there is an anticlinal of Aymestry rock which has the singular character of being folded or bent on an axal plane dipping to the east, so that the Ludlow rocks overlie the Old Red beds, while on the east the ridge of Wenlock limestone is seen dipping eastward, as if it were a superior stratum.

Such are some of the chief petrological or structural features to be observed in the field.

To attempt to discuss the causes of all the phenomena would lead us beyond the limits of our work, and such questions indeed belong more properly to a general Manual of Geology.

Most of those who take up the subject of Geology as a recreation may well be content to follow in the footsteps of others, but many again may possess a natural inclination to assist in the progress of the science.

They enter upon a somewhat dangerous path; so much has been done and published on various branches of geological enquiry, that often many volumes must be searched ere the facts brought to light can be regarded as new.

But there is plenty of work to be done if one do not attempt too much. The investigation of the intimate structure and method of formation of all kinds of rock, whether Aqueous or Igneous, needs many workers; Palæontology too needs many workers, who will devote especial attention to particular classes of animal life, and who will interpret the fossil species with sole reference to structure and without reference to age. Collectors are wanted who will collect with care, not, as a rule, by purchasing specimens from workmen, nor obtaining them from heaps of talus, but by personally extracting the fossils from the strata, and keeping accurate records of both stratum and locality. We can scarcely have too many lists of fossils from our strata in different localities. Here is work for the local geologist. A very great deal depends upon the investigations of those resident at or near localities where fossils may be obtained: they are best able to make collections, to study the present influence in the immediate district of denuding agents, and to estimate the annual waste, whether inland, by rain and rivers, or on the coast by atmospheric agents and sea.

Those who do not live in districts favoured with fossils, may devote themselves to microscopic examination or to indoor palæontological research.

One great drawback, and it is a very great one, is the want of sympathy that scientific men frequently feel, who, isolated in the country, find no one near to take an interest in their work. They must, however, be content to let it interest them, and when after long labour they can produce interesting results, their work will surely be appreciated.

Economic bearings of Geology.

Among the Economic purposes of Geology are its applications to Engineering, Architecture, Agriculture, and Mining.

In regard to drainage and water-supply, in the formation of canals, and in the making of roads, cuttings, and tunnels, a knowledge of Geology is most useful.

So also in the selection of building stones, where the mechanical structure of the rock has to be attended to.

Our Geological Maps display the superficial exposures of Limestones for building purposes and to be burnt for lime; of Marls for agricultural purposes; of Clays and Loams used in the manufacture of bricks, tiles, and pottery; of Slates for roofing and other purposes; of Marbles for the sculptor and for ornamental purposes; and of Granites used for building, for road metal, &c.

The prospects of Coal and the supply of Metals are questions towards the solution of which Geology lends great assistance.

There are, however, a host of minor applications of Geology to the Arts and Manufactures, which have been mentioned in the body of the work.

The relation between health and geology is also a point which has in recent years received a good deal of attention, and maps have been published and memoirs written to show the relations between certain forms of disease and geological structure—even between geology and lunatics! It is well known, indeed, that a gravelly, sandy, or chalky soil is more healthy than a clay foundation, because the former are pervious to water, and the latter is impervious. On the former there is less consumption than on the latter, as Mr. Whitaker and Dr. Buchanan have clearly demonstrated: the artificial removal of sub-soil water has, however, done much to equa-

lize the conditions. Again, the water-supply is a most important subject, for in some small country villages and towns the inhabitants suffer very much from its impurity. Situated, perhaps, on elevated ground, with a good porous soil, they yet suffer because of the disgraceful state of the drainage, the wells being shallow and the sewage, even the churchyards, draining into them. The cause of teetotalism will not find many admirers when it is often the women and children who suffer most from drinking impure water, while the men, who take their beer, are less subject to disease.

Scientific bearings of Geology.

Among the many intellectual pleasures to be derived from a study of geology none surpasses that which we may derive from the contemplation of the varied forms of scenery, and in the effort to realize the causes by which it has been produced.

Those who have devoted a long time to unravelling the geological structure of a district, who have visited every exposure of rock, and traced out the boundaries between the several formations, who have determined their mutual relations and the extent of any disturbances, and made themselves familiar with the life-history of the rocks, are best able, perhaps, to appreciate the contrast of feeling when they turn from the examination of details in themselves interesting to but few, and give their minds to the contemplation of the grand changes in scene which such a knowledge enables them to picture.

The study of our present land-features takes us so much into the history of the past, that it opens up very many questions, and leads to not a few interesting thoughts.

We learn (as has been pointed out) that much of our scenery is due to the lithological characters of our rocks, to their capability of withstanding the wear and tear of running

water, and as much of their resisting power is due to induration and metamorphism, conditions which we know require a long lapse of time to produce them, we might conclude that in early times there was not so much diversity of feature. We may also conclude this to have been true, because the very diversity in the nature of our rocks, due both to their method of formation, and the subsequent changes they have undergone, can have been but feebly represented in earlier times.

It was Murchison's opinion that in those early periods (Palæozoic) when the same groups of animals appear to have been so widely diffused, there could have been no lofty mountains and equivalent deep seas, inasmuch as the latter would have operated as positive barriers to such wide extension of marine creatures.

We must, however, be cautious in accepting ideas of the wide distribution of species in former times, and we must also remember that the Palæozoic epoch was of enormous duration compared to the succeeding geological periods.

The life-history of each different stratum tells of a plan that as yet we can only dimly picture. But there is a succession in the forms of life, as we ascend the geological scale. Higher and higher forms of life appear, and yet the very lowest types often continue alongside of them. Various forms were suited to the ever-varying physical conditions. As these changed, some species migrated to more favourable areas, while some which were better fitted to endure the change remained—some varieties may have profited largely by the change, and they would doubtless be perpetuated and multiplied, well illustrating the doctrine which teaches the 'survival of the fittest in the struggle for existence.'

Darwinian Theory.—It may seem out of place here to refer to the great teachings of Darwin, but they have so important a bearing on the history of life, which is so intimately connected with geology, that I may perhaps do well to make some mention of them.

It is somewhat astonishing to remark the amount of misconception that generally prevails in regard to the writings of Darwin even among many would-be scientific individuals, and how very general the notion is that his main object has been to prove that men were descended from monkeys. But this astonishment dwindles away when we reflect how few have read his works with care, and how many who have read anything of them have read with preconceived opinions, and in a spirit of antagonism, disregarding in a great measure his careful array of facts, and attempting to ridicule his cautious inferences, and deductions.

The variation of species, and natural selection, or the survival of the fittest in the struggle for existence, are Natural History facts, and the consideration of these facts as brought prominently into notice by Darwin has led to the doctrine of the Evolution of Life being regarded as the 'Fundamental Truth of Biology.' When, therefore, we hear the subject treated of as chimerical and purely imaginary—a tale of fairy land, wherein a flea might be transformed into an elephant, or an antelope, by constantly stretching its neck, might become a giraffe—we feel how greatly misunderstood and misrepresented the doctrine has been. This may arise from the mistaken notion that it would allow any one form of life in process of time, and through many generations, to develop into any other. When we look, however, upon the forms of life as the modified descendants of pre-existing organisms, we consider their relationship one to another much in the same way as we consider that of our own species individually. The relationship we bear to one another is sometimes near, sometimes very distant, so that while in one case we trace our descent through but a single step, in another we are connected only through many distant generations. It is the same with the different forms of life: in each branch, starting from one type, variation has set in; but while some forms have changed, others have remained more or less stationary or altered in a different ratio, so that constantly divergent forms are derived from the original type, and these divergent forms must not be confounded as being derived one from the other, but only as being derived from the same parent source.

Of course it is a great question how far the theory of Evolution may be successfully applied, but no earnest student of nature can long adhere to the very unphilosophical notion of a series of special creations; and when we hear otherwise well-informed persons talking of the profanity of the Darwinian theory, and insisting on the *literal acceptation* of the Scriptural account of the Creation, we cannot help reminding them that, notwithstanding the undoubted figurative language in which the Mosaic cosmogony is recorded, that description is really far more consistent with the doctrine of Evolution than with one which requires constant special creations of different forms of life throughout time. So hard is it

to realize the truth of the old adage that 'Fact is often stranger than Fiction.'[1]

The results of Palæontological investigation are ever bringing to light forms intermediate between those which previously seemed separated by a wide barrier. And not the least interesting branch of the subject is the comparison between the forms of life now existing in different portions of the world, with those found in different formations, and to trace in the present seas and oceans, and on the present continental areas and islands, lingering types of different ages in the past.

Antiquity of Man.—With the advent of man it is generally considered that the investigations of the geologist cease, and those of the anthropologist or archæologist commence; but the geologist has to deal with the most recent deposits; he has to study the deposits now forming in order to explain those of past times; and as all remains of organic origin or derivation are termed fossils when they are or have been entombed in sediment, so we must regard as fossils those works of man which have been discovered in the old accumulations of our caverns and river-valleys.

That the advent of man took place very much earlier than our forefathers imagined is a point about which there can be no question whatever; and although this conclusion is repugnant to many minds of a conservative nature who are unable to realize the facts upon which it is founded, it is nevertheless a conclusion which is fully established as true.

'Though we cannot yet make out clearly the relation of man to the Glacial period, or explain the gap between Palæolithic and Neolithic deposits, this we do know—that man lived in this country and throughout Western Europe with the lion and hairy elephant, the hyæna and woolly

[1] This notice is taken from a review by the author in the *Geological Magazine*, vol. x. p. 278.

rhinoceros. He was probably more or less nomadic, following the urus and the elk, and shifting from place to place as they migrated with the seasons. In his weapons of warfare and of the chase he resembled the dwellers on the shores of Arctic seas, and judging from the associated animals he probably lived in an age when continental conditions and higher mountains produced much greater extremes of climate than are found in the same countries now. In many places he probably followed hard on the receding glaciers, before the advance of which, perhaps, his ancestors retreated. Although we cannot assign a date to his first appearance, we must refer him to a period so remote that wide valleys have been scooped out and whole races of animals have been exterminated since his time, but how long it took to bring this about we cannot yet tell.'[1] (See p. 336.)

Mr. Croll[2] has, however, brought prominently into notice the subject of the causes of great changes of climate, pointing out that they may be attributed to the varying relations of the earth to the sun—to changes in the eccentricity of the earth's orbit. And he has shown that among the most important agencies affecting climate, which must be influenced by such changes, would be the deflection of ocean currents. To such causes our glacial epoch was due; and as astronomical data would place it at a period beginning about 240,000 years ago, and extending down to about 80,000 years ago—if further researches confirm the existence of man during, and perhaps before, the glacial period (and there seems good reason to believe that they will do so), we must not hesitate to assign to our forefathers an antiquity considerably greater than that even now attributed to them.

[1] *Cave Hunting.* By W. Boyd Dawkins. (1874.) See also *The Ancient Stone Implements, Weapons, and Ornaments of Great Britain.* By John Evans. (1872.)

[2] *Climate and Time in their Geological Relations.* (1875.)

Conclusion.

It is these questions of change of climate and condition and development of life that lend to geological science its higher interest.

The method of science demands the frequently long names and tedious descriptions of rocks or fossils—the more or less artificial classification and nomenclature—that make the science of geology seem so dry and uninviting to the 'uninitiated.'

But when we turn away from the matters of detail, when we pass on from the language and turn to the substance of the science, we find that even the purely economic aspect of geology furnishes interesting food for reflection. We cannot separate the many to us important and even necessary objects derived from our strata, from the evidences of design.

Nor could we well imagine an earth which had not undergone so great a series of changes as ours, before the advent of man, as likely to have furnished, out of about sixty so-called elementary substances, such an almost endless variety of useful products.

Such thoughts are but calculated to increase our reverence for the Great Architect of Nature, and to induce a feeling of humility which none can feel more than the student of science, who, whether with the aid of the telescope or with the microscope, knows no bounds in his study of the 'infinitely great,' or the 'infinitely little.'

When we endeavour to picture the many scenes that our tract of land has witnessed in the past, we find their counterparts in all climes and conditions of the present. Volcanoes, Glaciers, Coral Reefs, huge Lakes and Rivers, have all played their part in the history. And the rocks and fossils, the varied forms of hill and dale, remain as monuments of these changes.

In certain Boulder Clays and Gravels we find the relics of conditions similar to those affecting Greenland and Labrador at the present day. We have but to go into a Chalk-pit to study the conditions of the deepest ocean-bed. In the free-stone quarries of the Oolitic hills we sometimes find the evidence of old coral reefs, and some of the organic remains forcibly remind us of the existing flora and fauna of Australia. If we turn to the Red cliffs of Dawlish and Teignmouth, and to the salt-mines of Cheshire, the scene changes to large lakes such as the Caspian and Aral—lakes formerly connected with the sea. Again, we can study sub-tropical vegetation in the heaps of refuse thrown out from our Coal-mines. In still earlier periods we find that the scene constantly changes—the secretions of the Coral animal, the sands of the sea-shore, the sediments formed in lakes, and the lava and ashes of volcanoes, all form part of our Welsh and Cumberland mountains; and when we clamber over these old hills, and know that they are older than even the Alps and Himalayas, we can well feel that the story of English and Welsh Geology may vie in interest with that of any other part of the world.

Those, therefore, who, in their rambles along our country lanes, or over the hills of our beautiful island, can in the quarry or boss of rock read something of the marvellous changes that have in remote times affected the land; those even who can find some trace of a long past in the rocks that pave our streets or roof our houses, cannot fail to find that an inexhaustible mine of real happiness has been opened up for them.

APPENDIX.

A. GLOSSARY OF TERMS AND ADDENDA.

[N.B. This Glossary is intended to furnish an explanation of some geological terms whose meaning has not been given in the body of the work. (See Index.) It also contains the explanation of some few terms which, although not used in this book, may be met with in reading geological papers. To the student, however, Page's *Handbook of Geological Terms* and Bristow's *Glossary of Mineralogy* are indispensable works of reference in-doors.]

Aërial. Of or belonging to the air; produced or accumulated by wind.

Aqueous. Formed or deposited under water or through the agency of water.

Arenaceous. Sandy.

Argillaceous. Clayey.

Bed. A layer of any kind of rock.

Bituminous. Containing bitumen (a hydro-carbon); it is sometimes misapplied to ordinary coal, which contains no bitumen.

Bog Iron-ore. A loose, earthy form of Limonite.

Bone Bed. Any layer made up to a large extent of bones, either entire or fragmentary and rolled.

Botryoidal. Applied to concretions resembling a bunch of grapes.

Brackish. Applied to an admixture of fresh and salt water.

Brash. Stone.

Breaks. Indications at a certain locality of an interval of time unrepresented by any sedimentary deposit; proved by the absence of a deposit which was laid down elsewhere, or by evidence of erosion between two formations.

Breccia. A rock composed of angular fragments cemented together.

Buck's Horn Marble. Devonian limestone from Torquay containing *Stromatopora*.

Buhrstone or Burrstone. A vesicular siliceous rock, used for millstones, &c.

Calcareous or Calciferous. Containing carbonate of lime.

Chalcedony. A variety of quartz containing opal, and occurring usually in a mammillated or botryoidal form.

Chert. An impure kind of flint, of varied colour, often breaking with a flat or splintery, and seldom with a conchoidal fracture. The term Hornstone is used synonymously. Fossil shells, corals, and wood are frequently replaced by chert.

Chiastolite. A variety of Andalusite (Silicate of Alumina).

Chloritic. Sometimes applied to strata which have a green colour or contain green grains; the term properly signifies that the rock contains Chlorite (hydrous silicate of magnesia, alumina, and protoxide of iron).

Clunch. A provincial term for any coarse clay.

Combe (Cwm). A term applied to narrow up-land valleys which are frequently dry.

Conchoidal. Shell-like—applied to the fracture of flints and some other rocks, which exhibit convex fractures often like a *mactra* or some other bivalve mollusc.

Concretions. Nodules of any mineral matter.

Cone in Cone. A concretionary form of clay-ironstone, or argillaceous carbonate of iron. (See p. 384.)

Contemporaneous. Formed during or belonging to the same period.

Coprolites. Literally, petrified dung or fæces; often misapplied to phosphatic nodules which are of inorganic origin.

Cosmogony. This term is applied to inquiries and speculations concerning the origin of the earth.

Dendritic. Arborescent: possessing markings or appearances resembling trees.

Denudation. Wearing away, excavation, or erosion of certain rocks so as to expose or lay bare others.

Deposit. Any rock formed of material once held in suspension in water, or in the atmosphere, and arranged in layers.

Detritus. A term generally applied to an accumulation of loose material worn from or *rubbed off* rocks.

Disintegration. Any breaking up of rocks by atmospheric influence.

Dyke. The term Dyke is sometimes applied to the material filling fissures, faults or joints in any rock, as Dykes of Liassic, Rhætic, or other material may fill fissures or veins in the Carboniferous Limestone. It is more generally used in speaking of Igneous rocks which have been intruded among stratified rocks and form walls or dykes; such dykes of igneous rock may also occur in granite.

Emery. A greyish-black variety of Corundum (Alumina).

Enaliosauria. Used to designate the extinct marine saurians.

Erosion. Excavation or wearing away.

Estuary. A wide tidal mouth of a river.

Fairy Loaf. *Ananchytes ovatus,* a fossil sea-urchin found in the Chalk.

Feather-stone. Marble (Devonian limestone) found near Newton Abbot, and containing the Coral *Favosites polymorpha.*

Ferruginous. Containing iron; often applied to rocks which weather red or rusty.

Firestone. Any stone capable of withstanding heat.

Fissile. Capable of being split.

Floetz Class. A German term formerly applied to the Secondary strata, because the beds most usually occur in flat horizontal layers.

Fluviatile. Belonging to or formed by a river.

Fluvio-marine. Partly of freshwater (river) and partly of marine origin.

Freestone. Any stone, whether sandstone or limestone, which is capable of being freely cut or dressed.

Green earth. An earthy variety of Chlorite.

Gypseous. Containing gypsum (Hydrous sulphate of lime).

Hæmatite. Per-oxide of iron.

Heterocercal. Applied to fishes with unequally lobed tails.

Homocercal. Applied to fishes with equally bilobate tails.

Hone. Hones or oilstones generally consist of a fine-grained and compact slate-rock; they are sometimes called Whet-slates or Whetstones. Snake-stone is a speckled variety sometimes called Water-of-Ayr stone: it is used for polishing copper-plates, and by inlayers of stone for the later stages of polishing, the final rub being usually done with putty-powder (oxide of tin). Novaculite, as its name implies (*Lat.* novacula, a razor), is a variety chiefly used for sharpening razors.

Horizon. A term used to designate the particular level or position at which a certain stratum or fossil may occur in a formation.

Ichthyodorulite. Fossil fin-spines of fishes.

Ichthyolite. Any portion of a fossil fish.

Igneous. Of or belonging to 'fire': formed by volcanic agency.

In situ. In its natural position or place.

Intercalated. Interposed or placed between.

Iron-pyrites or Pyrites. Sulphide of Iron.

Jasper. An impure and opaque form of silica, coloured red, yellow or brown by oxides of iron.

Jet. A resinous variety of lignite.

Jew Stone. A name given to the top bed of White Lias (Sun bed) in parts of Somersetshire.

Lacustrine. Belonging to or deposited in a lake.

Lenticular. Lens-shaped.

Lignite. A form of fossilized wood.

Limonite. Hydrated per-oxide of iron.

Lithodomous. Applied to Mollusca which have the power of making cavities or burrows in rocks, &c.

Littoral. Belonging to or formed on the sea-shore.

Lydian Stone. A very siliceous rock, containing carbon, which gives it a grey or black colour, hence it is sometimes known as Black Chert.

Matrix. The rock in which any fossil or mineral is embedded.

Medial. A term used by Conybeare and Phillips for the Carboniferous strata; the Supermedial order included most of the Secondary rocks, and the Submedial order the Lower Palæozoic strata.

Mesozoic. Signifies 'middle life' as distinguished from Palæozoic and Kainozoic.

Metamorphic. Signifying altered form or structure.

Moraine. The detritus or stony material brought down by glaciers.

Moraine profonde. The material formed under land-ice.

Nodule. A concretion of mineral matter.

Organic Remains. Any fossil remains exhibiting the structure of plants or animals.

Paper Shale. Very finely-laminated shale.

Paramoudra. A term used for the large flints which occur in the Chalk of Norfolk, and which are sometimes called pot-stones. (See p. 247.) It was introduced from Ireland by Dr. Buckland, and is considered by some to be derived from the legend of Saturn swallowing the stone in mistake for Jupiter.

Parbold Stone. Yoredale Rocks, Newbrough, Northumberland.

Pennystone Ironstone Nodules. Nodules found in the Coal-measures of Coalbrook-dale; they often yield fossils when split open—impressions of fern leaves, fruits of *Lepidodendron*, king-crabs, insects, &c.

Physical. Natural: used with especial reference to the properties of inorganic substances.

Pit. Applied to any artificial boring or excavation, as a Coal-pit, a Marl-pit, or a Gravel-pit.

Pinnel. Local name given to the Lower Boulder Drift in the north-west of England and Wales. Rammel and Sammel are local names similarly applied.

Pomfret series. An old name applied to the Poikilitic Strata.

Pot-lids. Concretionary masses of sandstone of a lenticular form.

PRIMORDIAL. Signifying the *first order*, and sometimes applied to the earliest fossiliferous strata.

PROTOZOIC. Signifying first-life: sometimes applied to the earliest fossiliferous strata.

PYRITIC. Coated with or replaced by Iron-pyrites.

QUARRY. Any artificial excavation made in the working of stone.

QUARTZ. This is almost pure silica, and occurs both in crystals and massive or granular. Rock crystal is the purest form of quartz.

QUICKSAND. A loose and shifting or 'running' sand.

RADDLE or REDDLE. An earthy form of Hæmatite.

ROCHE MOUTONNÉE. A rounded eminence which has been smoothed or polished by glacial action, by the 'gritty base' of a glacier.

ROCK. Term applied by geologists to all materials which help to form the crust of the earth, whether clay, sand, gravel, or stone.

ROTH-LIEGENDE. A German term signifying 'Red layers,' and applied to the Lower Permian rocks.

RUBBLE. Soil mixed with angular and rounded fragments of the underlying rock.

SACCHAROID or SACCHARINE. Having a texture like loaf-sugar.

ST. CUTHBERT'S BEADS. Loose joints of Encrinites.

SCARP. A steep or precipitous face of a hill.

SECTION. The term Section in Geology is applied to any artificial excavation, boring or cutting, or natural cliff or bank, in which some geological stratum or set of strata has been exposed or proved. The term Horizontal Section is applied to the diagrams showing the geological structure of a country along a given line. The term Vertical Section is used to indicate the succession of beds at any given spot, as might be exhibited in a deep-boring or well; or a vertical section might be constructed by putting together in one column the several strata that crop out successively across a country.

SEGREGATION. Applied to the separation of various minerals into distinct aggregations or nodules.

SEPTARIA. Nodules of argillaceous limestone or clay-ironstone, divided internally by cracks filled with mineral matter, usually calc-spar. They are sometimes called Cement-stones.

SILICEOUS. Containing silica.

SILT. Fine sandy mud.

SOAPSTONE. Soapstone or Steatite is a variety of Talc. It is used at Swansea in the manufacture of porcelain, and in other places for various ornamental purposes.

SPICULA. Pointed needle-shaped bodies.

STIPER STONES. A celebrated ridge in Shropshire, whose stony masses, says Murchison, 'appear to the artist like insulated Cyclopean ruins

jutting out upon a lofty moorland, at heights varying from 1,500 to 1,600 feet above the sea.' They are fragments of a thick band of siliceous sandstones, which though in parts veined, altered and fractured, and occasionally passing into crystalline quartz rock, yet form an integral portion of the overlying schistose formation, and contain fragments of *Lingulæ*. (D. Page.)

STRATIGRAPHICAL. Concerning the description of or arrangement into strata.

STROMATOLOGY. Term proposed to embrace the history of the stratified rocks.

SUB-AËRIAL. Formed or produced on the surface of the land as distinguished from the water.

SYNCHRONOUS. Belonging to the same period, or occurring at the same time.

TALC. A pearly, white, grey, or green mineral, having a greasy feel; it is a hydrous bisilicate of magnesia.

TALUS. Used to designate the heaps of loose material which may have accumulated at the base of a cliff or quarry.

TERRESTRIAL. Of or belonging to the earth, or accumulated on the earth's surface.

TRANSITION CLASS. A term applied by the older school of geologists to the Cambrian, Silurian, and Devonian rocks.

WIGHT, ISLE OF, PEBBLES. Chalk-flints, containing sponges, &c.

ZECHSTEIN. A German term signifying 'Mine stone,' and applied to the Upper Permian rocks.

B. SYNOPSIS OF THE ANIMAL KINGDOM WITH ESPECIAL REFERENCE TO FOSSIL FORMS.[1]

SUB-KINGDOM **VERTEBRATA.**

PROVINCE I. *MAMMALIA.*

Order 1. Primates	Bimana	Man.
	Quadrumana	Ape, Lemur, *Macacus.*
2. Cheiroptera		Bat, Flying Fox.
3. Insectivora		Hedgehog, Shrew, Mygale, Mole, *Palæospalax, Spalacodon.*
4. Rodentia		Rat, Hare, Rabbit, Beaver, *Trogontherium.*
5. Hyracoidea		Hyrax, *Hyracotherium.*
6. Ungulata	Artiodactyla	Pig, Hippopotamus, Deer, Ox, Ovibos, *Anoplotherium.*
	Perissodactyla	Horse, Rhinoceros, Tapir, *Coryphodon, Lophiodon, Palæotherium.*
7. Toxodontia		*Toxodon.*
8. Sirenia		Manatee, Dugong, *Halitherium.*
9. Proboscidea		Elephant, *Mastodon, Deinotherium.*
10. Carnivora		Seal, Bear, Badger, Glutton, Wolf, Fox, Hyæna, Lion, *Machairodus.*

[1] This table is arranged chiefly according to the classification by Professor Huxley, given in the *Student's Manual of Geology* by Jukes and Geikie. Some of the Classes, &c., having no fossil representatives are omitted. The extinct genera, or those found only in a fossil state, are given in *italics.* For details the Student should consult Nicholson's *Manual of Palæontology.*

Order 11.	Cetacea	Whale, Porpoise, *Belemnoziphius*, *Zeuglodon*, *Squalodon*, *Balænodon*.
12.	Edentata	Sloth, Ant-eater, Armadillo, *Glyptodon*, *Megatherium*, *Mylodon*.
13.	Marsupialia	Kangaroo, Opossum, *Microlestes*, *Amphitherium*, *Phascolotherium*, *Plagiaulax*, *Spalacotherium*, *Stereognathus*.
14.	Monotremata	Echidna, Ornithorhynchus.

Province II. *SAUROPSIDA*.

Class 1. *AVES*.

Order 1.	Saururæ	*Archæopteryx*, *Odontopteryx*.
2.	Ratitæ	Ostrich, Apteryx, *Dinornis*, *Æpiornis*.
3.	Carinatæ	Plover, Gull, Pigeon, Swift, Eagle, *Lithornis*, Parrot, Stork, Kingfisher, *Halcyornis*.

Class 2. *REPTILIA*.

Order 1.	Ornithoscelida	*Deinosaurus*, *Iguanodon*, *Megalosaurus*, *Cetiosaurus*, *Thecodontosaurus*, *Palæosaurus*, *Hylæosaurus*.
2.	Pterosauria	*Pterodactylus*.
3.	Dicynodontia	*Dicynodon*, *Oudenodon*.
4.	Crocodilia	Alligator, Crocodile, *Stagonolepis*, *Teleosaurus*.
5.	Plesiosauria	*Plesiosaurus*, *Pliosaurus*.
6.	Lacertilia	Lizard, *Rhynchosaurus*, *Protorosaurus*, *Mosasaurus*, *Telerpeton*, *Hyperodapedon*.

7. Ophidia	Python, Rattlesnake, *Palæophis.*
8. Chelonia	Tortoise, Turtle.
9. Ichthyosauria	*Ichthyosaurus.*

PROVINCE III. *ICHTHYOPSIDA.*

CLASS 1. *AMPHIBIA.*

Order 1. Labyrinthodonta	*Labyrinthodon, Cheirotherium, Archegosaurus, Anthracosaurus, Dendrerpeton, Mastodonsaurus.*
2. Batrachia	Frog, Toad.

CLASS 2. *PISCES.*

Order 1. Dipnoi	Lepidosiren, Ceratodus.
2. Ganoidei	Sturgeon, Polypterus, *Palæoniscus, Lepidotus, Cephalaspis, Pteraspis, Coccosteus, Pterichthys, Cœlacanthus, Osteolepis, Megalichthys, Holoptychius.*
3. Teleostei	Eel, Salmon, Cod, *Beryx, Osmeroides, Platax.*
4. Elasmobranchii	Shark, Ray, Cestracion, *Onchus, Hybodus, Acrodus, Otodus, Carcharodon, Psammodus, Cochliodus, Pleuracanthus, Myliobatis.*
5. Marsipobranchii	Lamprey.
6. Pharyngobranchii	Amphioxus.

SUB-KINGDOM **ANNULOSA.**

PROVINCE I. *ARTHROPODA.*

CLASS 1. *INSECTA.*

Beetles, Butterflies.

CLASS 2. *MYRIAPODA.*

Centipede, *Xylobius, Euphoberia.*

CLASS 3. *ARACHNIDA.*

Scorpion, Spider, *Eoscorpius.*

CLASS 4. *CRUSTACEA.*

Order 1. Podophthalmia (Decapoda) . .	Crab (Brachyura), *Palæinachus, Xanthopsis*; Lobster (Macrura), *Anthrapalæmon, Eryon, Glyphæa.*
2. Ostracoda and Phyllopoda (Entomostraca)	Cythere, Cypris, *Beyrichia, Leperditia,* Estheria; *Hymenocaris, Dithyrocaris, Ceratiocaris.*
3. Pectostraca (Cirripedia) . . .	Barnacles (Lepadidæ), Pollicipes, Scalpellum; Acorn Shells (Balanidæ).
4. Merostomata	*Pterygotus, Hemiaspis, Slimonia, Eurypterus* (Eurypterida); King Crab, Limulus, *Belinurus* (Xiphosura).

5. Trilobita	Trilobites, *Acidaspis*, *Agnostus*, *Ampyx*, *Asaphus*, *Calymene*, *Encrinurus*, *Homalonotus*, *Illænus*, *Ogygia*, *Olenus*, *Phacops*, *Sphærexochus*, *Trinucleus*.
6. Edriophthalmia	Isopods, Amphipods.

Province II. *ANNULATA*.

Class 5. *ANNELIDA*.

Serpula, Lob-worm, *Arenicola*, *Cornulites*.

Province III. *ANNULOIDA*.

Class 6. *SCOLECIDA*.

Tape-worm, Rotifer.

Class 7. *ECHINODERMATA*.

Order 1. Echinoidea	Sea-urchin, *Galerites*, *Ananchytes*, Micraster, Cidaris, Clypeus.
2. Ophiuridea	Sand-star, Ophiura, *Protaster*.
3. Asteroidea	Star-fish, *Palæocoma*, *Palæaster*, Goniaster.
4. Crinoidea	Crinoids (Encrinites, Stone- or Sea-lilies), *Platycrinus*, *Actinocrinus*, Pentacrinus, *Apiocrinus*, *Extracrinus*.
5. Blastoidea	*Pentremites*.
6. Cystidea . . .	*Cryptocrinus*, *Apiocystites*.

SUB-KINGDOM **MOLLUSCA** (TESTACEA).

PROVINCE I. *ODONTOPHORA.*

CLASS 1. *CEPHALOPODA.*

Order 1. Dibranchiata	Argonaut, Cuttlefish, *Belemnites*, *Beloteuthis.*
2. Tetrabranchiata	Nautilus, *Ammonites*, *Clymenia*, *Lituites*, *Goniatites*, *Orthoceras*, *Phragmoceras*, *Cyrtoceras*, *Endoceras*, *Ancyloceras*, *Turrilites.*

CLASS 2. *PTEROPODA.*

Hyalæa, *Theca*, *Conularia*, *Tentaculites?*

CLASS 3. *GASTEROPODA.*

Order 1. Pulmo-Gasteropoda	Helix, Bulimus, Pupa, Physa, *Conulus*, *Bellerophon.*
2. Branchio-Gasteropoda	Patella, *Holopea*, Buccinum, Typhis, Voluta, Cypræa, Natica, Aporrhais, Cerithium, Turritella, *Holopella*, *Euomphalus*, Pleurotomaria.

PROVINCE II. *LAMELLIBRANCHIATA* (*Anodontophora* or *Conchifera*).

Ostrea, *Gryphæa*, Pecten, Lima, Avicula, Cardium, Mytilus, *Inoceramus*, Arca, *Anthracosia*, Leda, Nucula, Trigonia, Unio, *Hippurites*, Cyprina, Tellina, Mya, Pholadomya, Cucullæa, Modiola, *Orthonotus*, Pullastra, *Posidonomya*, *Pterinea.*

PROVINCE III. *MOLLUSCOIDA.*

CLASS 6. *BRACHIOPODA.*

Terebratula, Lingula, *Spirifer*, Rhynchonella, *Chonetes*, *Stringocephalus*, *Atrypa*, *Pentamerus*, *Orthis*, *Discina* (*Orbicula*), *Obolella*, *Leptæna*, *Strophalosia*, *Strophomena.*

CLASS 7. *POLYZOA* (*Bryozoa*).

Flustra, Eschara, *Fenestella*, *Cellepora*, *Fascicularia.*

CLASS 8. *ASCIDIOIDA* (*Tunicata*).

SUB-KINGDOM **CŒLENTERATA.**

CLASS 1. *ACTINOZOA.*

Sea-anemones, Corals, Alcyonium, Tubipora, *Favosites*, *Cyathophyllum*, *Calceola*, Astræa, *Montlivaltia.*

CLASS 2. *HYDROZOA.*

Pipe-Corallines, Tubularia, Sertularia, *Palæocoryne*, *Oldhamia*, *Dictyonema*; *Graptolites*, *Rastrites*, *Didymograpsus.*

SUB-KINGDOM **PROTOZOA.**

PROVINCE I. *STOMATODA.*

CLASS 1. *INFUSORIA.*

Noctiluca, Vorticella.

PROVINCE II. *ASTOMATA.*

CLASS 1. *SPONGIDA.*

Euplectella, Sponges, Siphonia, *Ventriculites,* Cliona, *Stromatopora? Receptaculites?*

CLASS 2. *RADIOLARIA.*

Polycistina, Thalassicolla.

CLASS 3. *RHIZOPODA.*

Foraminifera; Globigerina, *Nummulites,* Orbitolites, *Eozoön.*

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[1] The 'Geological Record,' of which the first volume (for 1874) has been published, and which is edited by Mr. Whitaker, gives the titles and a short abstract of geological papers published during each year.

Errata.

Pages 82, 90, *for* Penyghent *read* Pennygant.
,, 83, line 5 from bottom, *before* 'A very detailed section' *insert* 'At Clifton.'
,, 112, line 3 from top, *for* Sedgeley *read* Sedgley.
,, 165, line 4 from bottom, *for* Kelloway *read* Kellaways.
,, 349, line 14 from bottom, *for* Kirby Moorside *read* Kirkby Moorside.
,, 351, line 12 from bottom, *for* Cresswell *read* Creswell.

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